

**CHARACTERIZATION OF SALT AFFECTED SOILS IN
SELECTED LOCATIONS OF CAUVERY COMMAND AREA
AND STUDIES ON EFFECT OF NUTRIENT LEVELS AND
RATIOS ON GROWTH AND YIELD OF RICE IN GYPSUM
AMENDED SODIC SOIL**

**VIJAY KUMAR, C.
PALB 1092**

**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
UNIVERSITY OF AGRICULTURAL SCIENCES
BENGALURU
2015**

VISIT...

LANZAROTE
Caliente.COM

**CHARACTERIZATION OF SALT AFFECTED SOILS IN
SELECTED LOCATIONS OF CAUVERY COMMAND AREA
AND STUDIES ON EFFECT OF NUTRIENT LEVELS AND
RATIOS ON GROWTH AND YIELD OF RICE IN GYPSUM
AMENDED SODIC SOIL**

**VIJAY KUMAR, C.
PALB 1092**

*Thesis submitted to the
UNIVERSITY OF AGRICULTURAL SCIENCES, BENGALURU
in partial fulfillment of the requirements
for the award of the degree of*

Doctor of Philosophy

IN

SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

BENGALURU

APRIL, 2015



**Affectionately Dedicated to
My Family,
Friends
and
Beloved Teachers**

**UNIVERSITY OF AGRICULTURAL SCIENCES
DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
BENGALURU - 560 065.**

CERTIFICATE

This is to certify that the thesis entitled “**Characterization of salt affected soils in selected locations of Cauvery command area and studies on effect of nutrient levels and ratios on growth and yield of rice in gypsum amended sodic soil**” submitted by **Mr. VIJAY KUMAR, C., ID No. PALB 1092**, for the degree of **DOCTOR OF PHILOSOPHY in SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** to the University of Agricultural Sciences, Bengaluru, is a record of research work done by him during the period of his study in this University under my guidance and supervision and the thesis has not previously formed the basis of the award of any other degree, diploma, associateship, fellowship or similar other titles.

Bengaluru
April, 2015

(S. S. PRAKASH)
Major Advisor

**Approved by:
Chairman:**

(S. S. PRAKASH)

Members: 1.

(C. A. SRINIVASAMURTHY)

2.

(P. K. BASAVARAJA)

3.

(T. CHIKKARAMAPPA)

4.

(S. B. YOGANANDA)

(M. RAVICHANDRAN)
External Examiner

5.

(K. S. RAJASHEKARAPPA)

ACKNOWLEDGEMENT

I express my deep sense of gratitude and heartfelt respect to the chairperson of my advisory committee **Dr. S. S. Prakash**, Professor, Department of Soil Science and Agricultural Chemistry, College of Agriculture, V.C. Farm, Mandya for his invaluable guidance, constructive criticism and constant encouragement in this endeavor.

I would also like to express my profound gratitude to **Dr. C. A. Srinivasamurthy**, Professor & University Head, Department of Soil Science and Agricultural Chemistry and member of my advisory committee for his support and motivation throughout the course of my research work.

I wish to express my deep sense of gratitude to **Dr. P. K. Basavaraja**, Soil Chemist and Head, AICRP on STCR, Department of Soil Science and Agricultural Chemistry and member of my advisory committee for learned counsel, invaluable guidance and constructive criticism. I am greatly indebted to **Dr. T. Chikkaramappa**, Associate Professor, Department of Soil Science and Agricultural Chemistry, **Dr. S. B. Yogananda**, Senior Farm Superintendent, ZARS, VC Farm, Mandya, **Dr. K. S. Rajashekarappa**, Associate Professor, Department of Agricultural Engineering, College of Agriculture, UAS, GKVK, for their valuable advice and suggestions rendered as the members of my advisory committee.

I am grateful to **Dr. V. R. Ramakrishna Parama**, Professor and Head, Department of Soil Science and Agricultural Chemistry, UAS, GKVK, for support and valuable suggestions during the course of my research work.

I am grateful to **Dr. K. Sudhir, Dr. C. T. Subbarayappa, Dr. R. C. Gowda, Dr. H. C. Prakash, Dr. N. B. Prakash, Dr. T. Chamegowda, Dr. Sarala Kumari, Late Dr. T. H. Hanumantharaju** and other staff members of the Department of Soil Science and Agricultural Chemistry for their valuable suggestions, support and encouragement during my study period.

I would like to extend my sincere thanks to **Smt. H. K. Rathnamma and Sri. D. Srinivasamurthy** for their help and support rendered during my study period in the department.

I wish to express special thanks to **Dr. N. Srinivasa, Dr. Krishnamurthy, Dr. H. R. Umesh, Jayaram, M. T. Ramesh, Nagesh, Ravikumar, Atheefa, Veedashree, Laxmiakka and other worker of V.C. Farm** for their help and support rendered during my research.

I would like to extend my sincere thanks to **Manjunatha, Nethradhaniraj, Ramachandrappa, Krishnachari, Subramani, Vijayamma, Krishna, Kantharaju, Ravi, Anjenappa and N. B. Shylaja** for their constant help throughout my study period.

I would like to extend my sincere thanks to **Mr. G. S. Praveen**, Research Associate, Sujala-III project and **Dr. Chandrashekaraiah**, Entomologist for helping in preparation of Krigging maps.

I am extremely grateful to **Dr. P. K. Basavaraja** and **RKVY project**- “Increasing agricultural productivity by amelioration of problematic soils” for providing financial assistance to carry out my research work and AICRP on STCR for providing lab facility for analysis work during my research period.

Words are not enough to express my gratitude towards my beloved Grandparents **Smt. Hanumakka and Sri. Chikkalakshmaiah and sons** for their support and encouragement during my study. I am very grateful to god for giving me caring and dearest parents **Smt. Vinodamma and Sri. Chikka Mariyappa** and dearest brother **Sridhara** and sister **Bhanupriya** for their unswerving support throughout my life.

I wish to express my special thanks to my classmates **Karthika, Mohammed, Nalina, Prabhudev, Punithraj, Sandya and Yogendra**, senior and junior friends **Anil Kumar, Shiva Kumar, Shilpashree, Harish Babu, Vijaybharathi, Mahendra Kumar, Veeranagappa, Satebulla, Arun Kumar, Dinesh, S. S. Singh, N. C. Ravi, Sada, Shivanna, Prashantha, Kumarnaik, Vinay, Babu, Chandrakumar, Eresh, Sidharam Patil, Umesh, Srinivasa, D. K., Mahesh, Shamirkhan, Hemanth, Nagaveni, Chandrakanth, Mamatha** and my Jr. friends from Mandya (**Arun, Prakyath, Balaji and Rakesh**) for their help and support during my research period.

I express my sincere gratitude to **University of Agricultural Sciences, Bengaluru** for all the facilities and it makes me immensely proud and honored to be a student of this legendary and prestigious University.

Finally, I offer my heartfelt thanks to all other source of contribution that might have inadvertently been left out.

THANK YOU ONE AND ALL.....

Bengaluru

(VIJAY KUMAR, C.)

April, 2015

**Characterization of salt affected soils in selected locations of Cauvery
command area and studies on effect of nutrient levels and ratios on growth
and yield of rice in gypsum amended sodic soil**

Vijay Kumar, C.

ABSTRACT

Survey of salt affected soils in four selected locations of Cauvery Command Area indicated that soils are sandy clay loam to clay in texture, slightly acidic to alkaline in reaction (pH 6.2-10.6) with ECe in the range between 0.4 and 11.7dS/m. Soils were low to medium in organic carbon, N, P, K, Ca, Mg, S and micronutrients (Zn, Cu, Fe, Mn and B). Profile studies showed that soil pH, organic carbon and available N decreased with depth. Sodium was the most dominant cation and the ESP of the soils ranged from 1.1 to 58.6. The lowlands have higher sodium and ESP than uplands. The per cent samples falling under salinity and alkalinity or both were 71, 72, 65 and 83 in site 1, 2, 3 and 4, respectively.

Field experiments were conducted at ZARS, V. C. Farm, Mandya during *Kharif* 2013 and summer 2014 to assess the growth and yield response of rice to nutrient levels and ratios in gypsum amended sodic soil. The experiment were laid out in a randomized complete block design with nineteen treatment combinations and replicated thrice. The results revealed that application of gypsum @ 100% GR and 150:50:50 kg NPK/ha (3:1:1) recorded significantly higher grain (5.37 t/ha) and straw (6.79 t/ha) yield of rice, nutrient content and uptake (129.5, 35.6 and 84.3 kg NPK ha⁻¹) as compared to other nutrient levels and ratios. Further higher secondary and micronutrients content and uptake, nutrient use efficiency, higher gross and net monetary returns and higher B:C ratio (1.86) and decreased pH, ECe and ESP were recorded in the same treatment.

The study clearly showed that in sodic soils, application of gypsum @ 100% GR and NPK (150:50:50 kg/ha) is more beneficial in enhancing the crop yield, crop productivity as well as soil fertility.

Department of Soil Science and Agricultural Chemistry
UAS, GKVK, Bengaluru – 560065

(S. S. Prakash)
Major advisor

ಕಾವೇರಿ ಅಚ್ಚುಕಟ್ಟು ಪ್ರದೇಶದಲ್ಲಿನ ಆಯ್ದ ಸ್ಥಳಗಳಲ್ಲಿ ಲವಣಯುಕ್ತ ಮಣ್ಣುಗಳ ವರ್ಗೀಕರಣ ಹಾಗೂ ಜಿಪ್ಸಂ ಉಪಚರಿಸಿದ ಕ್ಷಾರ ಮಣ್ಣಿನಲ್ಲಿ ಭತ್ತದ ಬೆಳವಣಿಗೆ ಹಾಗೂ ಇಳುವರಿಯ ಮೇಲೆ ಪೋಷಕಾಂಶದ ಮಟ್ಟ ಮತ್ತು ಅನುಪಾತಗಳ ಪರಿಣಾಮದ ಅಧ್ಯಯನ.

ವಿಜಯ್ ಕುಮಾರ್, ಸಿ.

ಪ್ರಬಂಧದ ಸಾರಾಂಶ

ಕಾವೇರಿ ಅಚ್ಚುಕಟ್ಟು ಪ್ರದೇಶದಲ್ಲಿನ ಆಯ್ದ ನಾಲ್ಕು ಲವಣ ಪೀಡಿತ ಮಣ್ಣಿರುವ ಸ್ಥಳಗಳಲ್ಲಿ ಸರ್ವೇಕ್ಷಣೆಯನ್ನು ಮಾಡಲಾಯಿತು. ಅಧ್ಯಯನ ಪ್ರದೇಶದ ಬಹುತೇಕ ಮಣ್ಣುಗಳ ಕಣರಚನಾ ವಿನ್ಯಾಸವು ಮರಳುಯುಕ್ತ ಜೇಡಿಗೋಡಿನಿಂದ ಜೇಡಿ ಇರುವುದು ಕಂಡು ಬಂತು. ಮಣ್ಣಿನ ರಸಸಾರವು ಆಮ್ಲೀಯತೆಯಿಂದ ಕ್ಷಾರಯುತವಾಗಿದ್ದು (6.2 ರಿಂದ 10.6 ರಸಸಾರ), ಸಾರೀಕೃತ ವಿದ್ಯುತ್ ವಾಹಕತ್ವವು 0.4 ರಿಂದ 11.7 ಡೆಸಿ ಸೈಮನ್/ಮೀ ಇದೆ. ಮಣ್ಣಿನಲ್ಲಿ ಸಾವಯವ ಇಂಗಾಲ, ಸಾರಜನಕ, ರಂಜಕ, ಪೋಟಾಶ್, ಸುಣ್ಣ, ಮೆಗ್ನೀಷಿಯಂ, ಗಂಧಕ ಮತ್ತು ಲಘು ಪೋಷಕಾಂಶಗಳ ಅಂಶವು ಕಡಿಮೆಯಿಂದ ಮಧ್ಯಮ ಪ್ರಮಾಣದಲ್ಲಿರುತ್ತವೆ.

ಮಣ್ಣಿನ ಪಾರ್ಶ್ವದೃಶ್ಯ ಅಧ್ಯಯನ ಮಾಡಿ ಸಂಗ್ರಹಿಸಿದ ಮಣ್ಣಿನ ಮಾದರಿಗಳ ರಸಸಾರ, ಸಾವಯವ ಇಂಗಾಲ ಮತ್ತು ದೊರೆಯುವ ಸಾರಜನಕವು ಮೇಲ್ಪದರದಿಂದ ಕೆಳಪದರಗಳಿಗೆ ಹೋದಂತೆ ಇಳಿಮುಖವಾಗಿ ಕಡಿಮೆಯಾಗಿರುವುದು ಕಂಡು ಬಂದಿದೆ. ಈ ಮಣ್ಣುಗಳಲ್ಲಿ ಸೋಡಿಯಂ ಅಂಶವು ಪ್ರಭಾವೀ ಧನ ವಿದ್ಯುತ್‌ಕಣವಾಗಿದ್ದು, ಸೋಡಿಯಂ ವಿನಿಮಯ ಸಾಮರ್ಥ್ಯ ಪ್ರಮಾಣವು ಶೇ. 1.1 ರಿಂದ 58.6 ರಷ್ಟಿರುತ್ತದೆ. ಎತ್ತರ ಪ್ರದೇಶಗಳಿಗೆ ಹೋಲಿಸಿದಾಗ ಹೆಚ್ಚಿನ ಸೋಡಿಯಂ ಹಾಗೂ ಸೋಡಿಯಂ ವಿನಿಮಯ ಸಾಮರ್ಥ್ಯ ಪ್ರಮಾಣವು ತಗ್ಗು ಪ್ರದೇಶಗಳಲ್ಲಿ ಹೆಚ್ಚಾಗಿರುವುದು ದಾಖಲಾಗಿದೆ. ಸ್ಥಳ 1, 2, 3 ಮತ್ತು 4 ರ ಮಣ್ಣಿನ ಮಾದರಿಗಳಲ್ಲಿ ಚೌಳಿ ಮತ್ತು ಕ್ಷಾರೀಯತೆಯು ಶೇಕಡಾ 71, 72, 65 ಮತ್ತು 83 ರಷ್ಟು ಕಂಡು ಬಂದಿರುತ್ತದೆ.

ಜಿಪ್ಸಂ ಉಪಚರಿಸಿದ ಕ್ಷಾರ ಮಣ್ಣಿನಲ್ಲಿ ಭತ್ತದ ಬೆಳವಣಿಗೆ ಮತ್ತು ಇಳುವರಿ ಮೇಲೆ ಪೋಷಕಾಂಶಗಳ ಮಟ್ಟ ಹಾಗೂ ಅನುಪಾತಗಳಿಂದ ಆಗುವ ಪರಿಣಾಮವನ್ನು ಕಂಡುಹಿಡಿಯಲು, 2013 ರ ಮುಂಗಾರು ಮತ್ತು 2014 ರ ಬೇಸಿಗೆಯಲ್ಲಿ ವಲಯ ಕೃಷಿ ಸಂಶೋಧನ ಕೇಂದ್ರ, ವಿ.ಸಿ. ಫಾರಂ, ಮಂಡ್ಯದಲ್ಲಿ ಕ್ಷೇತ್ರ ಪ್ರಯೋಗಗಳನ್ನು ಕೈಗೊಳ್ಳಲಾಯಿತು. ಈ ಕ್ಷೇತ್ರ ಪ್ರಯೋಗಗಳು ಹತ್ತೊಂಭತ್ತು ಉಪಚಾರಗಳನ್ನೊಳಗೊಂಡಿದ್ದು ಮೂರು ಬಾರಿ ಪುನರಾವರ್ತಿಸಿ ಆರೌಸಿಬಿಡಿ ವಿನ್ಯಾಸದಲ್ಲಿ ರೂಪಿಸಲಾಯಿತು. ಶೇ 100 ರಷ್ಟು ಜಿಪ್ಸಂ ಅವಶ್ಯಕತೆ ಮತ್ತು 150:50:50 ಕೆಜಿ ಪ್ರತಿ ಹೆ, ಸಾರಜನಕ, ರಂಜಕ, ಪೋಟಾಶಿಯಂ ಉಪಚರಿಸಿದ ತಾಕುಗಳಲ್ಲಿ ಹೆಚ್ಚಿನ ಧಾನ್ಯದ ಇಳುವರಿ (7.37 ಟನ್ ಪ್ರತಿ ಹೆ), ಹುಲ್ಲಿನ ಇಳುವರಿ (6.79 ಟನ್ ಪ್ರತಿ ಹೆ), ಪೋಷಕಾಂಶಗಳ ಅಂಶ ಮತ್ತು ಗ್ರಹಿಕೆಯು (129.5, 35.6 ಮತ್ತು 84.3 ಕೆಜಿ ಪ್ರತಿ ಹೆ, ಸಾರಜನಕ, ರಂಜಕ, ಪೋಟಾಶಿಯಂ) ಇತರೆ ತಾಕುಗಳಿಗೆ ಹೋಲಿಸಿದಾಗ ಗಣನೀಯವಾಗಿ ಹೆಚ್ಚಾಗಿರುವುದು ಈ ಸಂಶೋಧನೆಯಿಂದ ತಿಳಿದುಬಂದಿದೆ. ಇದೇ ಉಪಚಾರದಲ್ಲಿ ಹೆಚ್ಚಿನ ಪೋಷಕಾಂಶಗಳ ಬಳಕೆ ಸಾಮರ್ಥ್ಯ, ಒಟ್ಟು ಮತ್ತು ನಿವ್ವಳ ಆದಾಯ ಮತ್ತು ಹೆಚ್ಚಿನ ಆಯ : ವ್ಯಯದ ಅನುಪಾತವು (1:1.86) ದಾಖಲಾಗಿದ್ದು ಮಣ್ಣಿನ ರಸಸಾರ, ವಿದ್ಯುತ್ ವಾಹಕತೆ, ವಿನಿಮಯ ಸೋಡಿಯಂನ ಶೇಕಡಾ ಪ್ರಮಾಣವು ಕಡಿಮೆಯಾಗಿರುವುದು ದಾಖಲಾಗಿರುತ್ತದೆ.

ಈ ಅಧ್ಯಯನದಿಂದ ತಿಳಿದುಬಂದ ಅಂಶವೇನೆಂದರೆ ಕ್ಷಾರಯುಕ್ತ (ಸೋಡಿಕ) ಮಣ್ಣಿನಲ್ಲಿ ಶೇ 100 ರಷ್ಟು ಜಿಪ್ಸಂ ಅವಶ್ಯಕತೆ ಮತ್ತು 150:50:50 ಕೆಜಿ ಪ್ರತಿ ಹೆ, ಸಾರಜನಕ, ರಂಜಕ, ಪೋಟಾಶಿಯಂ (3:1:1 ಅನುಪಾತ) ಉಪಚರಿಸಿದ ತಾಕುಗಳಲ್ಲಿ ಭತ್ತದ ಇಳುವರಿ ಮತ್ತು ಉತ್ಪಾದಕತೆಯನ್ನು ಹೆಚ್ಚಿಸಲು ಹಾಗೂ ಮಣ್ಣಿನ ಫಲವತ್ತತೆಯನ್ನು ವೃದ್ಧಿಸಲು ಪ್ರಯೋಜನಕಾರಿಯಾಗಿರುತ್ತದೆ.

ಮಣ್ಣು ವಿಜ್ಞಾನ ಮತ್ತು ಕೃಷಿ ರಾಸಾಯನ ಶಾಸ್ತ್ರ ವಿಭಾಗ

ಕೃಷಿ ವಿಶ್ವವಿದ್ಯಾನಿಲಯ, ಗಾ.ಕೃ.ವಿ.ಕೇ,

ಬೆಂಗಳೂರು-560 065

ಮುಖ್ಯ ಸಲಹೆಗಾರರು

(ಎಸ್. ಎಸ್. ಪ್ರಕಾಶ್)

CONTENTS

SL. NO.	CHAPTER	PAGE NO.
I	INTRODUCTION	1-4
II	REVIEW OF LITERATURE	5-37
III	MATERIAL AND METHODS	38-59
IV	EXPERIMENTAL RESULTS	60-154
V	DISCUSSION	155-181
VI	SUMMARY	182-186
VII	REFERENCES	187-211
	APPENDIX	212-252

LIST OF TABLES

Table No.	Title	Page No.
3.1	Number of surface and subsurface soil samples collected and the number of profiles excavated in each site.	40
3.2	Meteorological data indicating monthly normal, actual and deviation during 2013 at ZARS, V.C. Farm, Mandya.	48
3.3	Meteorological data indicating monthly normal, actual and deviation during 2014 at ZARS, V.C. Farm, Mandya.	49
3.4	Initial properties of soil of the experimental site at ZARS, V.C. Farm, Mandya.	51
4.1	Physico-chemical characteristics of the surface and subsurface samples of salt affected soils in Cauvery command area.	61
4.2	Exchangeable sodium percentage (ESP), Ca:Mg, Ca:Na ratio and ESI of the surface and subsurface samples of salt affected soils in Cauvery command area.	64
4.3	Water soluble ions content of the surface and subsurface samples of salt affected soils in Cauvery command area.	66
4.4	Organic carbon and nutrient status of the surface and subsurface samples of salt affected soils in Cauvery command area.	70
4.5	Micronutrient status (mean and range) in surface and subsurface samples of salt affected soils in Cauvery command area.	72
4.6	Correlation matrix for some selected soil characters at 0-15 cm depth.	75
4.7	Correlation matrix for some selected soil characters at 15-30 cm depth.	76
4.8	Physical properties of selected soil profiles in salt affected soils of site 1.	77
4.9	Physical properties of selected soil profiles in salt affected soils of site 2.	79

Table No.	Title	Page No.
4.10	Physical properties of selected soil profiles in salt affected soils of site 3.	81
4.11	Physical properties of selected soil profiles in salt affected soils of site 4.	83
4.12	Chemical properties of selected soil profiles in salt affected soils of site 1.	85
4.13	Chemical properties of selected soil profiles in salt affected soils of site 2.	86
4.14	Chemical properties of selected soil profiles in salt affected soils of site 3.	87
4.15	Chemical properties of selected soil profiles in salt affected soils of site 4.	89
4.16	Water soluble cations and anions content of selected soil profiles in salt affected soils of site 1.	95
4.17	Water soluble cations and anions content of selected soil profiles in salt affected soils of site 2.	96
4.18	Water soluble cations and anions content of selected soil profiles in salt affected soils of site 3.	97
4.19	Water soluble cations and anions content of selected soil profiles in salt affected soils of site 4.	98
4.20	Available nutrient status of selected soil profiles in salt affected soils of site 1.	101
4.21	Available nutrient status of selected soil profiles in salt affected soils of site 2.	102
4.22	Available nutrient status of selected soil profiles in salt affected soils of site 3.	103
4.23	Available nutrient status of selected soil profiles in salt affected soils of site 4.	104
4.24	Correlation matrix for some selected soil properties of profile in the study sites.	107

Table No.	Title	Page No.
4.25	Effect of NPK levels and ratios on plant height and number of tillers per hill of rice crop in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	109
4.26	Effect of NPK levels and ratios on number of productive tillers per hill and panicle length of rice in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	111
4.27	Effect of NPK levels and ratios on number of seeds per panicle and test weight of rice in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	112
4.28	Effect of NPK levels and ratios on grain and straw yield of rice in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	114
4.29	Effect of NPK levels and ratios on N, P and K concentration (%) of rice grain in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	116
4.30	Effect of NPK ratios and levels on Ca, Mg and S concentration (%) of rice grain in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	118
4.31	Effect of NPK levels and ratios on Na (%), Zn and Cu concentration (mg kg^{-1}) of rice grain in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	119
4.32	Effect of NPK levels and ratios on Fe, Mn and B concentration (mg kg^{-1}) of rice grain in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	120
4.33	Effect of NPK levels and ratios on N, P and K concentration (%) of rice straw in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	121
4.34	Effect of NPK levels and ratios on Ca, Mg and S concentration (%) of rice straw in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	123
4.35	Effect of NPK levels and ratios on Na (%), Zn and Cu concentration (mg kg^{-1}) of rice straw in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	124
4.36	Effect of NPK levels and ratios on Fe, Mn and B concentration (mg kg^{-1}) in rice straw in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	125

Table No.	Title	Page No.
4.37	Effect of NPK levels and ratios on N, P and K uptake (kg ha^{-1}) by rice crop in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	127
4.38	Effect of NPK levels and ratios on Ca, Mg and S uptake (kg ha^{-1}) by rice crop in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	129
4.39	Effect of NPK levels and ratios on sodium (kg ha^{-1}), Zn and Cu uptake (g ha^{-1}) by rice crop in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	130
4.40	Effect of nutrient levels and ratios on Fe, Mn and B uptake (g ha^{-1}) by rice crop in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	132
4.41	Nutrient use efficiency of rice as influenced by nitrogen, phosphorus and potassium levels and ratios in gypsum amended sodic soil in rice-rice cropping system.	134
4.42	Effect of NPK levels and ratios on soil pH, electrical conductivity and organic carbon content of soil (0-15 cm) after the harvest of rice crop in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	136
4.43	Effect of NPK levels and ratios on soil pH, electrical conductivity and organic carbon content of soil (15-30 cm) after the harvest of rice crop in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	137
4.44	Effect of NPK levels and ratios on available N, P and K content (kg ha^{-1}) of soil (0-15 cm) after the harvest of rice crop in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	139
4.45	Effect of NPK levels and ratios on available N, P and K content (kg ha^{-1}) of soil at 15-30 cm depth after the harvest of rice crop in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	140
4.46	Effect of NPK levels and ratios on exchangeable-Ca, Mg and available S content of soil (0-15 cm) after the harvest of rice crop in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	143
4.47	Effect of NPK levels and ratios on exchangeable-Ca, Mg and available S content of soil (15-30 cm) after the harvest of rice crop in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	144

Table No.	Title	Page No.
4.48	Effect of NPK levels and ratios on exchangeable sodium and DTPA extractable zinc and copper (mg kg^{-1}) content of soil (0-15 cm) after the harvest of rice crop grown in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	146
4.49	Effect of NPK levels and ratios on exchangeable sodium and DTPA extractable zinc and copper (mg kg^{-1}) content of soil (15-30 cm) after the harvest of rice crop grown in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	147
4.50	Effect of NPK levels and ratios on DTPA extractable iron, manganese and available boron (mg kg^{-1}) content of soil (0-15 cm) after the harvest of rice crop grown in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	149
4.51	Effect of NPK levels and ratios on DTPA extractable iron, manganese and available boron (mg kg^{-1}) content of soil (15-30 cm) after the harvest of rice crop grown in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	150
4.52	Effect of NPK levels and ratios on exchangeable sodium percentage of soil (0-15 and 15-30 cm) after the harvest of rice crop grown in gypsum amended sodic soil during <i>Kharif</i> 2013 and summer 2014.	152
4.53	Economics (Rs. ha ⁻¹) of rice cultivation as influenced by NPK levels and ratios in gypsum amended sodic soil in rice-rice cropping system.	153

LIST OF FIGURES

Sl. No.	Particulars	Between Page No.
1	Location map of the study area	38-39
2a	Sampling maps of site 1, site 2, site 3 and site 4 produced by ordinary krigging.	39-40
2b	Elevation maps of site 1 (A), site 2 (B), site 3 (C) and site 4 (D) produced by ordinary krigging.	39-40
3	Plan and layout of the field experiment.	52-53
4	Depth wise variation in sand and clay percentage in different profiles.	155-156
5	Map of surface and subsurface soil pH, ECe and ESP of site 1 produced by ordinary krigging.	157-158
6	Map of surface and subsurface soil pH, ECe and ESP of site 2 produced by ordinary krigging.	157-158
7	Map of surface and subsurface soil pH, ECe and ESP of site 3 produced by ordinary krigging.	157-158
8	Map of surface and subsurface soil pH, ECe and ESP of site 4 produced by ordinary krigging.	157-158
9	Depth wise variation in pH value of different profiles	159-160
10	Depth wise variation in salt content ($\text{ECe} - \text{dS m}^{-1}$) of different profiles.	159-160
11	Map of surface and subsurface soil CEC, exchangeable sodium and ESI of site 1 produced by ordinary krigging.	160-161
12	Map of surface and subsurface soil CEC, exchangeable sodium and ESI of site 2 produced by ordinary krigging.	160-161
13	Map of surface and subsurface soil CEC, exchangeable sodium and ESI of site 3 produced by ordinary krigging.	160-161
14	Map of surface and subsurface soil CEC, exchangeable sodium and ESI of site 4 produced by ordinary krigging.	160-161
15	Depth wise variation in exchangeable Na ($\text{cmol [p}^+ \text{] kg}^{-1}$) value	160-161

Sl. No.	Particulars	Between Page No.
	in different profiles.	
16	Depth wise variation in CEC ($\text{cmol } [\text{p}^+] \text{ kg}^{-1}$) values in different profiles.	161-162
17	Depth wise variation in ESP values in different profiles	161-162
18	Effect of nutrient levels and ratios on grain and straw yield of rice crop.	170-171
19	Effect of nutrient levels and ratios on nitrogen, phosphorus and potassium uptake by rice crop.	173-174
20	Effect of nutrient levels and ratios on nutrient use efficiency of rice crop.	174-175
21	Economics (Rs. ha^{-1}) of rice cultivation as influenced by nutrient levels and ratio in gypsum amended sodic soil.	180-181

LIST OF PLATES

Sl. No.	Particulars	Between Page No.
1.	Soil profiles of study sites 1, 2 and 3.	40-41
2.	Soil profiles of study sites 3 and 4.	40-41
3.	General view of the experimental plot at B block, V.C. Farm, Mandya.	52-53

LIST OF APPENDIX

Appendix No.	Title	Page No.
1	Chemical properties of surface and subsurface samples in salt affected soils of site 1.	229-230
2	ESP, Ca:Mg, Ca:Na and ESI of surface and subsurface samples in salt affected soils of site 1.	231-232
3	Water soluble cations and anions content of surface and subsurface samples in salt affected soils of site 1.	233-234
4	Organic carbon and available nutrient status of surface and subsurface samples in salt affected soils of site 1.	235-236
5	Micronutrients status of surface and subsurface samples in salt affected soils of site 1.	237-238
6	Chemical properties of surface and subsurface samples in salt affected soils of site 2.	239-240
7	ESP, Ca:Mg, Ca:Na and ESI of surface and subsurface samples in salt affected soils of site 2.	241-242
8	Water soluble cations and anions content of surface and subsurface samples in salt affected soils of site 2.	243-244
9	Organic carbon and available nutrient status of surface and subsurface samples in salt affected soils of site 2.	245-246
10	Micronutrients status of surface and subsurface samples in salt affected soils of site 2.	247-248
11	Chemical properties of surface and subsurface samples in salt affected soils of site 3.	249-251
12	ESP, Ca:Mg, Ca:Na and ESI of surface and subsurface samples in salt affected soils of site 3.	252-254

Appendix No.	Title	Page No.
13	Water soluble cations and anions content of surface and subsurface samples in salt affected soils of site 3.	255-257
14	Organic carbon and available nutrient status of surface and subsurface samples in salt affected soils of site 3.	258-260
15	Micronutrients status of surface and subsurface samples in salt affected soils of site 3.	261-263
16	Chemical properties of surface and subsurface samples in salt affected soils of site 4.	264
17	ESP, Ca:Mg, Ca:Na and ESI of surface and subsurface samples in salt affected soils of site 4.	265
18	Water soluble cations and anions content of surface and subsurface samples in salt affected soils of site 4.	266
19	Organic carbon and available nutrient status of surface and subsurface samples in salt affected soils of site 4.	267
20	Micronutrients status of surface and subsurface samples in salt affected soils of site 4.	268
21	Cost of inputs used and price of output.	269

LIST OF ABBREVIATIONS

@	at the rate	kg	kilogram
⁰ C	Degree Centigrade	kg ha ⁻¹	kilogram per hectare
%	Per cent	m	Meter
Avail.	Available	m ²	square meter
C. D.	Critical Difference	m ³	cubic meter
Cl ⁻	Chloride	me L ⁻¹	milli equivalent per liter
cm	Centimeter	mg kg ⁻¹	milligram per kilogram
CO ₃ ⁼	Carbonates	mg l ⁻¹	Milligram per liter
cv.	Cultivar	mg L ⁻¹	milligram per liter
dS m ⁻¹	deci Siemens per meter	mm	millimeter
EC	Electrical conductivity	N	Nitrogen
ECe	Electrical conductivity of saturation extract	<u>N</u> NH ₄ OAC	Neutral Normal Ammonium Acetate
<i>et al.</i>	Co workers	Na	Sodium
<i>etc.</i>	Etcetera (so on)	NS	Non-significant
ESI	Electrochemical stability index	P	Phosphorus
ESP	Exchangeable sodium percentage	P ₂ O ₅	Phosphorus
Fig.	Figure	ppm	Part(s) per million
g kg ⁻¹	Gram per kilogram	q ha ⁻¹	quintal per hectare
g ha ⁻¹	Gram per hectare	RDF	Recommended dose of fertilizer
ha ⁻¹	Per hectare	Rs.	Rupees
HCO ₃ ⁻	Bicarbonates	S.Em±	Standard error of mean
g ⁻¹	per gram	SO ₄	Sulphate
K	Potassium	t	tonnes
K ₂ O	Potassium	t ha ⁻¹	tonnes per hectare

I. INTRODUCTION

One of the critical challenges world wide is the un-proportional growth of human population compared to that of food production. The maximization of crop production is therefore urgently required to overcome this imbalance. Globally, most of the land suitable for agriculture has been put under cultivation and horizontal expansion into new areas to increase food production is remote. Increasing the productivity per unit area in a farming system is one of the possible alternatives in sight.

Irrigation has played a significant role in increasing the productivity globally and in all the crops. Thus significant importance has been given for the expansion of irrigable area. In India, an area of 79.5 million hectares has been created as the potential irrigable area but the coverage is hardly 55 million hectares (Yadav, 1973). This gap is attributed mainly to the lower irrigation efficiency. At the same time, irrigation has brought several ill effects to the good cultivated areas by way of waterlogging and development of salt affected soils. Therefore, irrigation water could be a boon or bane depending on its use.

All soils contain some salts but when soils contain excessive concentrations of either soluble salts or exchangeable sodium or both, they are called salt affected soils (Conway, 2001). Over 10 per cent of the worlds land is salt affected (Szabolcs, 1989). “Salt affected soils” is a broad term covering a range of soils defined as saline, saline-sodic and sodic. When soils contain excessive concentrations of water-soluble salts, they are called saline. Sodic soils are low in soluble salts than saline soils but high in exchangeable sodium. On the other hand, saline-sodic soils contain both water-soluble salts and exchangeable sodium in large amounts.

Soil salinity/sodicity and waterlogging are the major problems of land degradation in irrigated area of the world. About 952 m ha of land in the world is under soil salinity and alkalinity of which 343.2 m ha is under salinity and 608.8 m ha under alkalinity (FAO, 1974). Salt-affected soils occur in more than 120 countries with variation in extents, nature and properties, and reducing 7 to 8 % of the productive capacity of the land (Yadav, 1973). In India, the salt affected area in the country as reported by Sharma

(1998) was 7.42 m ha (soil salinity plus alkalinity) of which 0.179 m ha area is in Karnataka.

Most of the current salt affected soils where crops are grown are located in low relief landscapes of arid and semi arid regions and coastal areas, characterized by dense populations, intensive agricultural activities, higher temperature and evapotranspiration often associated with insufficient leaching leading to greater salt accumulation. Accumulation of salts in such agricultural soils alters its physico-chemical properties, including pH, exchangeable sodium (Na_{exch}), electrical conductivity of the saturated paste (ECe), sodium absorption ratio (SAR), exchangeable sodium percentage (ESP), saturated hydraulic conductivity (Ks) and soil available water capacity (AWC). Consequently, mineral elements and water availability for plant growth and yield of most crops is affected.

It has been reported that excess concentration of exchangeable sodium and high pH values of soil decrease the permeability and infiltration capacity of soil through swelling and dispersion of clays as well as slaking of aggregates. These modifications inturn affect the yield of crops by affecting the availability of nutrients via specific (ionic stress) and non-specific (osmotic stress) effects, thus, jeopardizing the income of most farmers. But ever increasing demand for good quality land and water resources in the domestic and industrial sectors has resulted in an enhanced interest in the utilization of salt affected soils for food production to feed the teeming millions.

Agriculture today is facing competition for good quality land and water resources from domestic and industrial sectors. There is an urgent need to have comprehensive understanding and better contingency plans based on resource efficient, socio-economically viable and environmentally safe technologies to deal with salt affected soils and to improve productivity of such lands.

As per the projections made, an area of about 15.5 million ha is likely to be affected by the problems of water logging and soil salinity/sodicity in the irrigation commands of India by 2030 (CSSRI, 2011). In irrigated areas, the increased use of saline water together with poor management practices aggravates the problem, particularly

when there is inadequate drainage of water exceeding plant requirements. As the water table rises, salts stored within the soil profile are mobilized and carried towards the soil surface, resulting in salinization. These require an efficient technique to decrease the salinity in the upper soil layer for improved root growth and crop development. Gypsum application followed by surface flushing and/or vertical leaching may show promise for the amelioration of sodic soils.

Gypsum is conventionally used to reclaim alkali soil, as it serves as an amendment with the supply of soluble calcium for replacing sodium from the exchange complex. Other amendments that are commonly used are sulphur and pyrites, which acidify the soil environment and dissolve the native reserves of calcium in the soil and thus help in the reclamation of calcareous alkali soil.

The problem of low productivity of salt affected soils may be ascribed not only to their salt toxicity or damage caused by excess amounts of soluble salts but also arising from the low status of organic matter and available nutrients. Low availability of nutrients results from precipitation, transformation and fixation with soil minerals. Concerns about salinization/sodification risk and environmental quality and productivity of agro-ecosystems have emphasized the need to develop management practices that maintain soil resources.

Organic manure is commonly used as an amendment in problematic soil reclamation and it supply some of the nutrients that are deficient in problematic soils and also improve the physical properties of the soil. Farmyard manure and green manure are commonly used in the reclamation of salt affected soils.

The addition of inorganic fertilizer will increase the yield of crops. But the cost of fertilizers is increasing and it becomes difficult for the farmers to use them. Since the fertilizer is an expensive input, determination of its economical and appropriate dose to enhance crop productivity is imperative to fetch the maximum returns, resulting in higher profit for the growers. At present, the world is facing the shortage of nitrogenous and phosphatic fertilizers. Even when their supply is satisfactory, importance of increasing the use efficiency cannot be underestimated. Different varieties may have varying

responses to NPK fertilizers depending on their agronomic traits. The application of fertilizer either in excess or less than optimum rate affects both yield and quality to a remarkable extent (Manzoor *et al.*, 2006). The combination of organic and inorganic sources has been reported to be beneficial and quicker in the reclamation of alkali soils. A combination of gypsum and farmyard manure may prove to be the best amendment in certain problematic situations.

Some studies have shown that the use of gypsum on saline-sodic and sodic soils improves most of the properties and helps in leaching the salts into the lower layers. Although abundant literature on the effect of gypsum on sodic and saline-sodic soil is available [Anand Swarup (1991), Srinivasa (1999), Sunitha (2008), Joachim and Hubert (2010) and Sharma *et al.* (2011)], studies on the effects of gypsum and nutrient (NPK) levels and ratios in recently reclaimed sodic soils on rice growth and yield are inadequate. So, understanding the effect of gypsum and nutrient levels and ratios on soil properties and crop yield may be of importance in order to optimize farm management strategies by farmers practicing agricultural activities in such soils.

It was therefore felt necessary to study the effect of nutrient (NPK) levels and ratios on growth and yield of rice in gypsum amended sodic soil. Keeping these aspects in view, the present research entitled “Characterization of salt affected soils in selected locations of Cauvery command area and studies on effect of nutrient levels and ratios on growth and yield of rice in gypsum amended sodic soil” was conducted with the following objectives,

1. Characterization of salt affected soils in selected locations of Cauvery Command Area (CCA) with respect to physico-chemical properties.
2. To study the effect of different levels and ratios of nutrients with gypsum on properties of sodic soil.
3. To study the effect of different levels and ratios of nutrients with gypsum on growth and yield of rice grown in sodic soil.
4. To work out the cost economics of rice cultivation in sodic soils.

II. REVIEW OF LITERATURE

“Salt affected soils” usually occur in association with their normal counterparts, but distinguish themselves in having higher concentration of electrolytes and/or higher content of exchangeable sodium and poor to extremely poor fertility status, resulting in restricted availability and uptake of nutrients by plants (Szabolcs, 1989). The buildup of salt content in a soil, which is generally the case in any salt affected soil, may influence crop production in several ways through changes in the proportion of exchangeable and water soluble cations, soil reaction, physical properties of soil and osmotic and specific ion toxicity effects. These changes have a great bearing on the activity of ions and its effect on plant roots and soil microbes. Diagnosis and classification of salt affected soil is generally based on pH, electrical conductivity (EC) and exchangeable sodium percentage (ESP).

Characteristics and properties of salt affected soils and the effect of nutrients level on crop growth and yield in salt affected soil is important in order to understand the problems and plan proper scientific reclamation and nutrient management in such soils.

Review of literature pertaining to the above said aspects of investigations carried out in India and abroad has been presented briefly in this chapter under the following headings:

2.1 Salt affected soils and their origin

Salt affected soils are more extensive in arid and semi-arid regions compared to humid regions (Abrol and Yadav, 1988). The source of salts in salt affected soils comes from two main sources 1) primary or natural sources and 2) secondary or human factors (Michael and Paul, 2002).

Salinization is the process of accumulation of soluble salts as Cl^- and SO_4^{2-} of Ca, Mg, Na and K in soils resulting in EC_e of $> 4 \text{ dS m}^{-1}$ whereas alkalization involves the accumulation of sodium ions on the exchange complex of the clay to the extent of $>15\%$ ($\text{ESP} > 15$).

2.1.1 Primary salinization

Primary salinization is caused by naturally occurring salt deposits mostly in arid and semiarid areas. Primary salinization is the accumulation of salts as a result of natural processes such as weathering of parent materials and the deposition of marine salts carried by wind and rain. Some salt rich soils are released from weathering of saline parent rocks. Kelley (1951) considered sedimentary deposits, such as shale, sandstone, glacial, wind-borne materials and unconsolidated alluvium of various glacial ages, as the source of salts.

Poor drainage is another factor that usually contributes to the salinization of soils, it is the most common cause, and it may involve the presence of a high ground water table or low permeability of the soil. The high ground water table is often related to topography. Therefore, there are drainage basins that have no outlets to permanent streams. The drainage of salt-bearing waters away from the higher lands of the basin may raise the ground-water level to the soil surface on the lower lands, may cause temporary flooding, or may form permanent salty lakes. Under such conditions, upward movement of saline ground water or evaporation of surface water results in the formation of saline soil (Ashraf and Harris, 2005). Low permeability of the soil causes poor drainage by impeding the downward movement of water. Low permeability may be the result of an unfavorable soil texture or structure or the presence of indurated layers (Salliah and Pathmarajah, 2003).

2.1.2 Secondary salinization

Secondary salinization, the gradual build up of salt in previously salt-free topsoil, occurs in irrigated areas as salt is introduced into the soil with every round of irrigation. Part of the salt is leached below the root zone, but part of it remains in it. The capillary rise of salt-rich groundwater driven by high evaporation in summer brings salt to the surface. In command areas, the increased use of water together with poor management practices aggravates the problem, particularly when there is not sufficient drainage of water exceeding plant requirements. As the water table rises, salts stored within the soil profile are mobilized and carried towards the soil surface, resulting in salinization.

Secondary salinization has been intensified by change in land use, which means change from more water use plant to less water use plant cause water table rise, when irrigation water quality is marginal or worse (Salliah and Pathmarajah, 2003). In addition, when the drainage of the soil may not be adequate for irrigation, the ground-water table may rise from a considerable depth to a few feet of the soil surface in a few years due to irrigation. When the water table rises to 5 or 6 feet of the soil surface, ground water moves upward into the root zone and to the soil surface. Under such conditions, ground water, as well as irrigation water, contributes to the salinization of the soil. Deforestation, overgrazing, or intensive cropping, fertilizer and amendments applied to soils are other secondary salinity causes (Salliah and Pathmarajah, 2003).

2.2 Classification of salt affected soils

In India the soil scientists and agronomists use the well-known definition outlined by United States Department of Agriculture, USDA hand book No 60 (Richards, 1954). Bhargava *et al.* (1976) have grouped salt affected soils occurring in India into following two categories:

1. **Alkali soils:** Soils with pHs more than 8.5, ESP of 15 or more and preponderance of carbonates and bicarbonates of sodium. The ECe is limitless if originating from salts of alkali hydrolysis, otherwise less than 4 dS m^{-1} at 25°C . While, Abrol *et al.* (1980) suggested that pHs of 8.2 is more realistic diagnostic criterion for distinguishing sodic from non-sodic soils.
2. **Saline soils:** Soils having pHs less than 8.5, ESP less than 15 and preponderance of chlorides and sulphates of sodium, calcium and magnesium. The ECe is more than 4 dS m^{-1} at 25°C .

However, some overlaps of the above two categories conforming to saline-alkali soils have been noticed in the Indo-Gangetic plains and soils where brackish ground waters are used. Therefore, in a broad sense, Szabolcs (1989) has grouped salt affected soils as follows

1. The saline soils that develop under the influence of sodium salts with nearly neutral reaction.

2. The alkali soils that develop under the influence of electrolytes capable of alkali hydrolysis, mainly Na_2CO_3 and NaHCO_3 .
3. Acid sulphate soils composed mainly of $\text{Al}_2(\text{SO}_4)_3$ and $\text{Fe}_2(\text{SO}_4)_3$ salts.
4. Others types of salt affected soils, such as strongly degraded alkali soils with sub-soil salinization and potential salinization.

Alternate wet and dry seasons and the topographic conditions seem to be the contributing factors for formation of salt affected soils. In low-lying areas water gets accumulated during wet season and as a result of evaporation soil solution becomes concentrated and SAR of water increases. This results in increased exchangeable sodium and high pH. The displaced calcium precipitates at high pH. This process repeated over long periods results in sodic soil formation (Bhumbla, 1978).

The composition of salts is dependent on the rainfall of an area. With rainfall around 750 mm, carbonates and bicarbonates are the dominant anions followed by chlorides and sulphates, isohyets of 500-550 mm contained anionic composition of sulphates, chlorides and carbonates + bicarbonates. Below 300 mm isohyets chlorides and sulphates dominate with only traces of carbonates (Singh *et al.*, 1980). The salt affected medium exhibited the preponderance of neutral salts though distinctly alkali in nature (Mehta, 1983).

Many saline-sodic soils contain soluble carbonates besides the excess of neutral salts. Such soils manifest alkali soil properties. It is therefore, only prudent that the saline-sodic soils containing no soluble carbonates is grouped and managed as saline soils and the rest of them grouped and managed like alkali soils (Gupta and Abrol, 1990a).

2.3 Site characteristics of salt affected soil

The important site characteristics which influence formation of salt affected soils are slope or micro-relief, erosion, drainage, stoniness and land use.

Biswas and Gawande (1962) studied catenary soils of Chhattisgarh basin of Madhya Pradesh and reported that variation in colour and moisture status is a function of

slope. They observed that along the slope, depth of solum increased and soil reaction changed from acidic to alkali and texture becomes clay from sandy loam.

Murthy and Landey (1967) studied saline-alkaline soils of Bellary district in Karnataka locally called as 'Chuolu', 'Kari' and 'Jougu'. Chuolu and Kari soils were found in low-lands and depressions where rain water stands for long time due to restricted drainage. The soil 'Jougu' was found in depressions where water table was high and where soil remained saturated due to impervious sub soil horizon.

Gawande and Biswas (1977) reported that soil characteristics such as depth, colour, soil reaction, drainage, texture *etc.* are mostly influenced by the variation in land forms at micro level with specific reference to black cotton soils.

In a study on the effects of seepage and waterlogging on the development of saline and sodic soils in Bhadra project area of Karnataka, Bhadrapur and Sheshagiri Rao (1979) observed that all low land soils were saline-sodic due to seepage from uplands.

Gaikawad *et al.* (1985) reported that the impact of landform or elevation affects the soil depth, colour, slope, erosion, physico-chemical properties of soils and land use in Bhandara district in Maharashtra.

Sharma *et al.* (1997) reported that the soil properties such as pH, CaCO_3 , clay content, CEC and exchangeable cations were markedly influenced by the topography of the landscape.

2.4 Characterization of salt affected soils

Owing to the presence of excess salts and the absence of significant amounts of exchangeable sodium, saline soils generally are flocculated; and, as a consequence, the permeability is equal to or higher than that of non saline soils (Richards, 1954). Saline soils commonly have visible salt deposits on the surface and are sometimes called white alkali soils. While sodic soils can have a black colour due to the dispersion of organic matter, as well as a greasy or oily looking surface with little or no vegetative growth. These soils are often referred to as black alkali soils or slick spots. These soils correspond to Hilgard's "black alkali" soils and in some cases to "Solonetz," as the latter term

is used by the Russians (Richards, 1954). These soils are sticky when wet, nearly impermeable to water and have a slick look. As they dry, they become hard, cloddy and crusty.

Basu and Tagore (1954) noticed blackish colour on the soil surface and occasional white encrustation over the surface and found that the black colour was due to drying of salts usually with sodium carbonate.

The alkali soils were characterized by Sharma *et al.* (2011) as very deep with pale brown to light yellowish brown soil matrix and few to common yellowish brown mottles in the sub-surface horizons.

2.4.1 Particle size distribution

The variation in particle size with soil depth is a natural genetic process of horizon differentiation. However, the lateral variation in particle size distribution for each horizon over short distance results in a random or systematic heterogeneity that causes considerable variation in soil physical characteristics (Pal and Deshpande, 1987).

The salt affected soils of Vanivilas command area of Karnataka were generally light in texture at the surface and tend to become heavy with the depth (Mruthunjaya and Kenchanna Gowda, 1993).

While characterizing the soils of an irrigated river flood plain in eastern coastal region, Sahu and Mishra (1997) observed that sand and silt content in all the pedons decreased from the surface downwards whereas clay content gradually increased down the depth, indicating pedogenic soil development.

Bhaskar and Nagaraju (1998) observed textural change in soils of predominant slopes which indicated high degree of variability in vertical distribution of sand and silt contents and yielded high sand: silt ratio. The high degree of sodicity in these soils is due to presence of sodium carbonate and bicarbonate and resulted in high pH conditions.

In salt affected soils of Rajasthan, Sharma *et al.* (2004a) observed that there was a variation in the clay content of soils of different pedons. The per cent clay content was more in strongly saline soil followed by moderately, slightly, very slightly and non saline soils. Clay fraction in general was more concentrated in sub surface layer of various pe-

dons except soils of saline groups but the movement of clay has not been enough to contribute appreciable textural changes in the soil.

Verma *et al.* (2012) studied the soil of Trans Yamuna area in Etawah district, Uttar Pradesh. The results revealed that the soil texture varied from sand to sandy clay loam.

2.4.2 Chemical characteristics of soil

The chemical characteristics of soils classified as saline are mainly determined by the kinds and amounts of salts present. Ions most commonly associated with soil salinity include the anions chloride (Cl^-), sulphate (SO_4^{2-}), bicarbonate (HCO_3^-) and sometimes nitrate (NO_3^-) and the cations sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and sometimes potassium (K^+). The exchangeable sodium present in nonsaline-alkali soil may have a marked influence on the physical and chemical properties. As the proportion of exchangeable sodium increases, the soil tends to become more dispersed. The pH reading may increase, sometimes becoming as high as 10. The soil solution of nonsaline-alkali soils, although relatively low in soluble salts, has a composition that differs considerably from that of normal and saline soils (Richards, 1954).

According to Richards (1954) an electrical conductivity of the saturation soil extract (ECe) in excess of 4.0 dS m^{-1} is associated with saline soils. However, the terminology committee of the soil science society of America has lowered the boundary between saline and non-saline soils to 2.0 dS m^{-1} in the saturation extract (Girdhar, 1993).

Saline-sodic may contain appreciable quantities of soluble carbonates in addition to neutral salts, which manifest the alkaline soil properties. Hence, it is imperative that the former type of saline sodic soils be grouped and managed like saline soils in the beginning and the latter as alkaline soils (Gupta and Abrol, 1990).

Szablocs (1993) reported that lack of neutral soluble salts and predominance of sodium salts capable of alkaline hydrolysis, such as carbonate and bicarbonate of sodium along with others, sodic soils are associated with a high alkalinity, characterized by pH as high as 10.5.

Magnesium ions adsorbed on clays behaves like sodium, when its concentration in soil exceeds that of calcium, which may be as harmful as sodium, especially in soil characterized by dominance of fine textured clays Kadu *et al.* (1993) and Balpande *et al.* (1996).

Singh *et al.* (2000) studied the characteristics of old alluvial soils of Sone basin. The soils on upland physiography under immediate influence of the river Sone are loamy sand to sandy loam texture, low in OC, slightly acidic to neutral reaction (pH 6.4-6.7), lower CEC and exchangeable Mg and Na, while the soils on upland under immediate influence of Sirisia canal are clay loam to clay, low in OC, neutral to slightly alkaline in reaction (pH 6.7-7.5) and intermediate in CEC and exchangeable sodium. Further, the soils on lowland under the influence of the back waters of the river and canals in saucer-shaped physiography are characterized by clayey texture, low OC, alkaline reaction (pH 7.9 -10.2) and high EC (2.0-9.6 dS m⁻¹), CEC and exchangeable Mg and Na. In lowland soils, argillipedoturbation followed by salinization and sodiumization of various degrees are operative.

Sodic soil catena in the Shangani ranches exhibited a high degree of compaction, poor drainage status, restricted permeability and contained varying amounts of calcium carbonate (0.1 – 6.1%). Clay content increased in the profiles of the mid and upper catena compared to those in lower catenal positions. Soil pH ranged between 7.5 and 10.1, ESP ranging from 36.9 to 98.9 and EC values of all soils of the catena were ≤ 4.0 dS m⁻¹ (Mzezewa *et al.*, 2003).

The soils of Mula command area of Maharashtra were high in clay (36 to 57%), moderate to strongly alkaline (pH 8.2 to 9.5) in reaction with electrical conductivity of saturation extract varying from 0.70 to 6.52 dSm⁻¹, ESP from 3.9 to 27.0 % and high in calcium carbonate varying from 88 to 205 g kg⁻¹ (Kharche and Pharande, 2010).

Geetha Sireesha and Naidu (2013) studied the soils of Banaganapalle mandal of Kurnool district (Andra Pradesh). The results revealed that the soils were slightly alkaline to strongly alkaline (pH 7.9 to 8.7) in reaction, non-saline, deep to very deep in depth.

Texture, OC, CEC and base saturation were ranged from sandy clay loam to clay, 0.04 to 0.75%, 21.8 to 51.2 cmol (p⁺) kg⁻¹ and 51 to 99 %, respectively.

2.4.3 Soil pH

pH is a measure of the acidity or alkalinity of a substance. The range of pH for most soils is from 4 to 10. Soil pH is considered the single most important chemical property of soil because it affects the availability of essential plant nutrients.

Many researchers have reported that alkali or sodic soils are often associated with very high pH values (greater than 8.5 and in some case, as high as 10) While its value in saline soils and saline-sodic soils are <8.5 and above or below 8.5, respectively.

Saline soils generally have a pH less than 8.5. Bear (1964) attributed such low pH in saline soils to the presence of electrolytes and negative adsorption of anions responsible for decrease in the thickness of the double layer and suppression of hydrolysis of adsorbed Na to some extent. As a result, the hydroxyl ion concentration goes down, leading to reduced pH.

Kamil and Shainberg (1968) observed a higher pH in the absence of salts and attributed it to the production of more Al ions on clay surface as a result of increased dehydroxylation of Al-complex. These Al ions caused more Na ions to hydrolyse into solution, leading to a higher soil pH. However, Nakayama (1970) reported that the high pH values is caused under field conditions by Na bicarbonate-carbonate minerals present in alkali soils, which precipitate Ca and Mg carbonate during evaporation. While Gupta (1973) attributed the higher values of pH in a saturated paste (pHs) of alkali soils to the nature of electrolytes. The alkali soils contain predominantly sodium carbonate and sodium bicarbonates, which are weak electrolytes. On hydrolysis, the pH of weak electrolytes increases sharply. The higher concentration of sodium carbonate in alkali soils, which is the cause of high pH, was suggested to be originating by the reaction of exchangeable Na and CaCO₃ in low CO₂ and low salt system (Cruz-Romero and Coleman, 1975).

Pathak and Patel (1980) studied the characteristics of salt affected soils of Kaira district of Gujarat state. The values of ESP and pH were comparatively higher in lower

layers of salt affected areas. Similarly calcium carbonates and soluble boron were also noted to be in salt affected areas. The salinity was mainly Cl^- - SO_4 type.

The pH of salt affected soils of Vanivilas command area in Karnataka ranged from 8.5 to 11.0 (Mruthunjaya and Kenchanna Gowda, 1993), in Cauvery command area it was in the range of 8.1 to 10.1 (Srinivasa, 1999), in Keliveli of Purna valley of Maharashtra it ranged from 7.5 to 9.7 (Kewade *et al.*, 2005) and the pH of soils of Purna command area ranged from 8.1 to 10.7 ((More *et al.*, 1988) and in Krishnagiri Reservoir Project (KRP) area and Mettur dam Ayacut area of Tamil Nadu it ranged from 8.6 to 10.0 (Jayakumar *et al.*, 2012). While the pH of sodic soils in Kanpur regions of UP varied from 8.5 to 10.3 due to the presence of soluble sodium carbonate and bicarbonate (Tiwari *et al.*, 1983).

Samples from sodic soils of Karnal (Haryana) were investigated for the depth wise trend of soil pH by Kanwar and Sehgal (1962). They noticed that soil pH values were found to increase with the profile depth, which was quoted to be because of fluctuating water table and higher concentrations of sodium salts. Similar trend of results have been reported by Govindarajan *et al.* (1969) and Poonia and Bhumbla (1973). However, in clay loam soils and clay soils studied by Mediratta *et al.* (1985), the pH values decreased down the profile, indicating the start of sodification process from the upper layers. In addition to the above said definite trends, an irregular trend may also be observed, as noticed by More *et al.* (1988) in the salt affected soils of Purna Command Area of Maharashtra.

Sunitha *et al.* (2010) studied the characteristics of salt affected soils in Dodda Seebi tank command area of Karnataka. The soils were alkaline in reaction as pH in the surface soils (8.5 to 9.0) with a tendency to increase with depth.

2.4.4 Electrical conductivity (EC)

Electrical conductivity, the ability of a soil solution to carry electrical current, is used to measure soluble salt concentration and is reported in dS m^{-1} . When a solution extracted from saturated soil is 4.0 dS m^{-1} or greater, the soil is saline. The pH of these soils is generally less than 8.5, and sodium makes up less than 15 percent of the exchangeable

cations. On the other hand sodic soils are low in total salts ($<4 \text{ dS m}^{-1}$) but high in pH (>8.5) and ESP (>15).

In an investigation of salt affected soils, occurring in the northern parts of Gujarat, Barde and Gowalkar (1965) noticed surface soils to be free of salt problems and the EC values increased with depth. In another study, Sharma *et al.* (1968) also noticed a similar trend, where in EC value recorded in surface soil was zero and it was as high as 65 dS m^{-1} at a depth of 100cm. High electrical conductivity in lower depths was mainly due to leaching of salts from the upper layers and their accumulation in the lower depths on account of irrigation (Balpande *et al.*, 1996). Sahu and Dash (1993), while characterizing salt affected soils of Orissa, noticed that in profiles protected by embankments, EC values increased with the depth, while in the profile that was unprotected an opposite trend was noticed.

Mehta *et al.* (1981) diagnosed 230 soil samples from farmer's field with an EC (1:2.5) of more than 2 dS m^{-1} and pH more than 10 as alkali soils, though they could have been diagnosed as saline alkali soils.

On the contrary, Sahu *et al.* (1986) observed higher salt content in the surface samples of saline soils of Orissa due to brackish water and high ground water table. Vijaya Kumar *et al.* (2013) noticed EC value of 17.0 dS m^{-1} in the surface layer and 15.3 dS m^{-1} in the subsurface soil layer in Ongole division of Prakasam district, AP. Similar results have been reported by many authors in various parts of India (Jain and Saxena, 1975; Mediratta *et al.*, 1985).

Costa *et al.* (1991) reported that an increase in EC of irrigation water increased EC of saturation extract but carbonates and divalent ions reduced the EC of saturation extract due to precipitation of calcite and gypsum. They also observed irrigation water with higher SAR increased the EC of saturation extract, mainly due to higher sodium concentration relative to calcium and magnesium and the greater solubility of sodium salts than calcium and magnesium.

There are reports which show no definite trend in the vertical distribution of EC value. Walia and Rao (1996) reported that the electrical conductivity of the black soils

studied were very low ranging from 0.08 to 4 dS m⁻¹ and did not show any specific relationship with the depth.

The electrical conductivity value of sodic soils in Keliveli of Purna valley of Maharashtra ranged from 0.17 to 0.80 dS m⁻¹. Kewade *et al.* (2005), in North Western zone of Tamil Nadu it ranged from 0.2 to 1.2 dS m⁻¹ (Jayakumar, *et al.*, 2012) and in Vanivilas Command Area of Karnataka it varied from 1.83 to 3.68 dS m⁻¹. Singh *et al.* (2000) while characterizing the old alluvial soils reported that electrical conductivity of soils varied from 2 to 9.6 dS m⁻¹.

The conditions facilitating accumulation of salts in the surface horizons and the absence of leaching from surface to lower depths, have been found to be responsible for increasing trend of the EC values in profile stratum upwards, while leaching of salts by irrigation water to the deeper layers and absence of rapid capillary rise were responsible for lower EC value in the surface layer (Sharma *et al.*, 2004b). While, Kharche (1990) reported slight variation in EC with increasing depth due to leaching of salts from the surface through percolating water followed by evapo-transpiration resulting in the accumulation of salts in the surface horizon.

Sunitha *et al.* (2010) studied the characteristics of salt affected soils in Dodda Seebi tank command area of Karnataka. EC of the surface soils ranged from 1.94 to 2.78 dS m⁻¹ and found to increase below 30 cm depth owing to leaching and hydrolysis of salt on account of irrigation.

The salt affected soils in IGNP command, Rajasthan were neutral to slightly alkaline in reaction (pH 7.9 to 8.8). The E_{Ce} values were moderate (9.3 dSm⁻¹) to very high (40.3 dSm⁻¹) and decreased with depth (Mandal and Sharma, 2010).

The waterlogged and salt affected soils in Gandak command area of Bihar were severe alkaline in surface soil and moderately high pHs (9.1) at subsurface level (70 cm). The higher E_{Ce} values (19.7 dS m⁻¹) were found at surface and decreased gradually to 0.4 dS m⁻¹ at a depth of 1 m (Sharma *et al.*, 2011).

Vijaya Kumar *et al.* (2013) studied the salt affected soils of Ongole division, Prakasam district (Andhra Pradesh) were neutral to strongly alkaline (pH 6.5 to 9.1) in re-

action having electrical conductivity value higher in surface soils (17.0 dS m^{-1}) than sub-surface soil (15.3 dS m^{-1}).

2.4.5 Exchangeable sodium percentage (ESP)

Sodic soils have exchangeable sodium percentages of more than 15 while in saline soil it was less than 15. The exchangeable sodium present in sodic soil may have a marked influence on the physical and chemical properties. As the proportion of exchangeable sodium increases, the soil tends to become more dispersed. The pH reading may increase, sometimes becoming as high as 10.

In equilibration studies on some Vertisols, occurring in Malaprabha project area, Karnataka, Kotur and Sheshagiri Rao, (1987) noticed an inverse relationship between CEC and ESP. In the upper layers of soils, associated with lower CEC and ESP more sodium was adsorbed, while reverse was the case in lower horizons wherein soils had high CEC. Deshpande (1985) and Ballolli (1987) also made similar observations and attributed this trend of decrease in ESP with depth to increase in CEC values, favouring the preferential adsorption of divalent cations, leading to a decrease in SAR value with depths. The decrease in ESP with soil depth have also been reported by many other workers (Kuri, 1979; Srinath, 1979 and Mediratta *et al.*, 1985). This may also indicate the initiation of process of sodiumization of soil from surface downwards.

Sharma and Jha (1989) observed increased application of saline water resulting in higher CEC and ESP in the soil. This may be due to *in situ* mineral swelling and dispersion of clay particles and migration resulting in clogging of soil pores.

The ESP of the soils in Vanivilas command area ranged from 39.86 to 54.62 indicating alkali nature of these soils (Mruthunjaya and Kenchanna gowda, 1993) in Vertisols of Tungabhadra left bank command area in Karnataka state it varied from 8.5 to 31.0 and sodicity increased with depth (Patagundi *et al.*, 1996) and in Chamarajnagar taluk under Kabini track (Cauvery Command Area) indicated that the soils had pH of 9.06 and ESP of 40.8 per cent (Guruprasad, 2005).

Exchangeable sodium percentage was found to increase with increase in soil depth. An increase in exchangeable sodium percentage down the soils of Tungabhadra

command area in Karnataka was reported by Yerriswamy (1996). A trend of increase in ESP from soil surface downwards has been considered to indicate initiation of sodiumization process in a downward direction (Balpande *et al.*, 1996).

Girdhar (1996) observed that ESP increased significantly with an increase in residual sodium carbonate and its adverse effect become additive at higher SAR, RSC of soil extract was greater than the RSC of the leaching water, as a result adsorption of sodium significantly increased.

Mzezewa *et al.* (2003) revealed that the pH of sodic soil ranged from 7.5 to 10.1. Phenomenal increase in exchangeable sodium percentage ranging from 36.9 to 98.9 was recorded in the subsoil horizons of the profiles in upper catenal positions. There was a slight drop in ESP values in soils of the lower catena.

2.4.6 Organic carbon

Landey and Murthy (1967) studied the organic carbon content in black soils of East Vidarba region of Maharashtra and observed that it ranged between 0.27 and 1.03 per cent.

Murthy *et al.* (1982) reported that black soils are generally calcareous and organic matter content in black soil is low (0.42-0.50 per cent).

Kharche (1990) studied the organic carbon status of Nagpur district black soils and stated that organic carbon contents in the soils varied from 0.11 to 0.76 per cent. He further reported that as soil depth increases, organic carbon content decreases.

The surface soils recorded higher organic carbon values than sub-surface layers. High amount of organic carbon in surface soils could be attributed to dispersion of organic matter along with dispersed clay particles that comes to the soil surface during summer on account of capillary rise and gets deposited in isolated patches on soil surface. The decreased organic carbon content down the profile could also be attributed to the in situ incorporation of crop residues and addition of FYM and other organic manures to the soil surface every year. (More *et al.*, 1988 and Balpande *et al.*, 1996).

Sunitha *et al.* (2010) studied the organic carbon content of salt affected soils of Dodda Seebi tank command area. The results revealed that OC content was low which ranged from 2.59 to 4.60 g kg⁻¹ in the surface layers and decreased with depth due to organic matter dispersed slowly to the deeper depths and vice-a- versa during summer on account of capillary rise and get deposited in isolated patches on soil surface.

Vijaya Kumar *et al.* (2013) studied the organic carbon (OC) content in salt affected soils of Ongole division, Prakasam district of Andhra Pradesh. The OC content of soil ranged from 0.6 to 12.9 g kg⁻¹ (surface) and 0.5 to 10.8 g kg⁻¹ (subsurface). 72% of surface and 95% of subsurface soils had low (<0.5 g kg⁻¹) in OC which could be ascribed due to rapid decomposition and mineralization of organic matter in semi-arid climatic conditions. Similar results were reported by Suribabu *et al.* (2002) for A. Konduru mandal in Krishna district of Andhra Pradesh.

2.4.7 CaCO₃ equivalent (Alkaline Earth Carbonates)

Barde and Gowalkar (1965) reported that the per cent calcium carbonate in salt affected soils of North Gujarat increased with depth and the values were 0, 1.8, 6.7 and 20.5 at 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm depth, respectively.

Murthy (1988) reported the presence of calcium carbonate in Indian Vertisols either as concretion or in a finely powdered form which varied from 5 to 200 g kg⁻¹.

Sharma and Raychoudhari (1988) reported that there is gradual increase in CaCO₃ content with decrease in topographic level. Sehgal (1991) observed nodular CaCO₃ up to 20 per cent in black cotton soils. Solid phase calcium carbonate governed the P reactions and related to carbonate particle-size distribution.

Subbaiah and Manickam (1992) studied the genesis and morphology of Vertisols and noticed that the size and abundance of CaCO₃ concentration increases with soil depth.

Salt affected soils of southern Rajasthan were moderately shallow to very deep, sandy loam to clay loam in texture and calcareousness increased with depth (Sharma *et*

al., 2004a). A free CaCO_3 and higher amount of alkaline earth metal contributed to parent material (Sunitha *et al.*, 2010).

Rajendra *et al.* (2011) studied the physico-chemical properties of Mokala soil series of Rajasthan. The soils are neutral to alkaline in reaction (pH 7.7 to 8.9), EC ranged from 0.09 to 1.76 dS m^{-1} and CaCO_3 content of soils varied from 1.50 to 4.50 with a mean value of 3.13%.

The CaCO_3 was found as amorphous (1.4 to 2.1%) as well as concretion (2-6%) forms. The calcretes of recent origin were also found at a depth of 1m, indicating precipitation of sparingly soluble calcium salts under high pH and restricted drainage (Sharma *et al.*, 2011).

2.4.8 Nature of water soluble ions

Agarwal and Rammoorthy (1970) observed that in black soils, the $\text{Cl}^-:\text{SO}_4$ ratio was higher in surface layers of alkali soils than in normal soil. These observations indicated the accumulation of Cl^- owing to evaporation and protection from further leaching, due to heavy texture of the soils. The process of evaporation when rapid, as in case of arid and semi-arid regions will lead to concentration of carbonates and bicarbonates in the soil solution. With the increase in concentration of carbonates, Ca and Mg ions are precipitated and rendered less soluble. As a result the activity of Na increases which leads to the development of sodic soils (Kanwar and Kanwar, 1968).

Levy and Feighonbaum (1977) indicated that increased soluble sodium upon dilution was due to its replacement mainly by calcium and magnesium.

Bhadrapur and Sheshagiri Rao (1979) opined that water soluble cations decreased with depth in the saline and alkali soils of Tungabhadra left bank canal area. The concentration of water soluble cations in the studied pedons followed the order $\text{Na} > \text{Ca} > \text{Mg} > \text{K}$. This showed that water soluble Na was present in highest concentration. This is mainly due to higher solubility of Na salts compared to Ca, Mg and K salts. The results of present investigation with respect to concentration and distribution of water soluble cations closely synchronize with the observation made by More *et al.* (1988) and Balpande *et al.* (1996) in Purna Valley area of Maharashtra.

In the sodic soils of Kanpur region of Uttar Pradesh, carbonate was the dominant ion followed by bicarbonate, chloride and sulphate in all the profiles, but when bicarbonate was dominant the other ions followed the order: Chloride, carbonate and sulphate (Tiwari *et al.*, 1983).

In some salt affected soils of Bijapur district, Karnataka, sodium was found to be the dominant cation, followed by calcium and magnesium, while sulphate was the dominant anion in soil water extract. The tendency of sulphate to accumulate in the surface layer was attributed to the presence of sodium sulphate in surface layers, which is highly soluble compared to sulphates of calcium and magnesium (Ballolli, 1987). Chloride was the dominant anion followed by sulphate whereas bicarbonate content exceeded chloride in sodic profiles of Purna command area of Maharashtra (More *et al.*, 1988).

Sharma and Jha (1989) noticed that in salt affected soils of Indo-Gangetic plain, the sequence of soluble cations was $\text{Na}^+ > (\text{Ca}^{2+} / \text{Mg}^{2+}) > \text{K}^+$, while in normal soils the order was $(\text{Ca}^{2+}/\text{Mg}^{2+}) > \text{Na}^+ > \text{K}^+$. Among anions, bicarbonates were dominant, followed by sulphates, while a reverse order was evident in normal soils. Formation of sodium carbonate and bicarbonate, which favoured sodium adsorption on the exchange complex, was thought to be the main factor involved in sodification of the soils (Pal and Mandal, 1980).

Gupta and Abrol (1990a) reported that saline sodic soils may contain appreciable quantities of soluble carbonates in addition to neutral soluble salts, which manifest the alkaline soil properties.

Srinivasa (1999) characterized six sodic soil profiles of the irrigated areas of Vishweshawaraiah canal tract of Cauvery command area. The ionic composition with respect to water soluble ions indicated that sodium was the dominant cation in all the soil bodies. The sequence of soluble cations in the profiles were $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ and $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{CO}_3^{2-}$ anionic type.

Sharma *et al.* (2004a) studied the soluble ion composition of salt affected soils of southern Rajasthan. Among soluble ions Na^+ and Cl^- dominated and were followed by Ca^{2+} and HCO_3^- in the extract.

Sharma *et al.* (2005) characterized and classified the salt affected soils of Bhilwara district of Rajasthan. Among the soluble ions Na^+ and Cl^- dominated and were followed by Ca^{2+} and HCO_3^- in the extract.

Guruprasad (2005) characterized the nature of ions under Kabini tract of Cauvery command area. The ionic composition was in the order of $\text{Na} > \text{Ca} > \text{Mg} > \text{K}$ and SAR 3.9 to 19.6.

The delineation and characterization of waterlogged and salt affected soils in Gandak command area of Bihar by Sharma *et al.* (2011) revealed accumulation of CO_3^{2-} and HCO_3^- ions due to the presence of calcite and dolomite in soils. The presence of high sodium ions resulted in high pH.

2.4.9 Exchangeable cations and CEC

Amounts and proportions of the various exchangeable cations present markedly influence the physical and chemical properties of soils, their status being dependent on various factors like mineralogy, status of soluble cations, concentration of electrolytes and others.

Determination of sodicity and alkali status of sodic soils is important to know the amendment requirement of soils on scientific lines. In the literature, values of exchangeable Na^+ content in excess of the cation exchange capacity of the soils have been obtained by using conventional ammonium acetate method (Kanwar and Bhumbra, 1969).

Sehgal *et al.* (1968) reported that the exchangeable calcium and magnesium content in soils of Sutlej river basin, Punjab, decreased with depth and the values were 6.6 and 2.0, and 2.2 and 0.4 me 100 g^{-1} soil, respectively at surface and at one meter depth.

Exchangeable sodium was appreciably higher than predicted from the SAR values, higher ESP would be observed in the Mg-Na system than in the Ca-Na systems. Calcareousness and texture of soils also influence the ionic preferences of the two divalent cations (Girdhar and Yadav, 1982).

Katigenavar (1998) studied 12 soil profiles of Ghataprabha and Malaprabha irrigation projects in Karnataka. The soils investigated have been deteriorated on account of

high exchangeable sodium as revealed by chemical properties. Sodicity was the major problem prevailing in these soils. Regarding nutrient status, the soils were low in nitrogen while phosphorus and potassium were low to medium.

Sharma *et al.* (2004b) recorded that the CEC varied widely in saline soils in consequence of variation in their clay fraction compared to non saline soils where the CEC varied narrowly. Increased CEC value was observed in sub surface horizon. Contribution of clay fraction was more for CEC since the soils were low in organic carbon. Increased clay content provided more exchange sites to get the cations adsorbed on it.

Kawade *et al.* (2005) recorded the CEC of 43.5 to 58.0 cmol(p⁺)kg⁻¹ of soil in salt affected soils of Keliveli of Purna valley of Maharashtra .

Ram *et al.* (2010) studied the flood prone soils of eastern plains of Rajasthan. The results revealed that calcium and magnesium were the dominant exchangeable cations followed by sodium and potassium. The variation was small within the horizons but was large with profiles. ESP of soils varied from 5.3 to 27.6 indicating nitric characteristics of these soils. CEC of soils varied from 5.64 to 27.52 cmol(p⁺) kg⁻¹ with slight increase in B-horizon and then decreased with depth due to higher amount of illuviated clay and organic matter in B-horizon.

2.4.10 Nutrient status of salt affected soils

Salt affected soils usually contain less than 0.1 per cent organic matter, are thus poor in native available N and hence respond to applied N. The efficiency of N fertilizers in sodic soils is low, partly due to volatilization of the element as ammonia and partly due to sub-optimal plant growth that results owing to poor soil physical properties.

Nitant and Dargan (1974) reported that complete hydrolysis of urea at a pH of 10.4 was delayed by four days when compared with normal soils. This means a gradual supply of NH₄⁺ ions to the solution phase and consequently more volatilization losses. Soils with high pH values have shown positive influence on NH₃ losses (Fenn and Kissel, 1973). Losses of ammonia were higher at the field moisture range and in unreclaimed soils it generally ranged between 30 and 65 per cent depending upon the level of N applied and prevailing soil moisture conditions (Bhardwaj and Abrol, 1978; Rao and Batra,

1983). Symbiotic N fixation is also retarded in salt affected soils, due to sensitivity of microbes to high alkalinity and reduced growth of host plants. Bhardwaj (1975) reported that though rhizobia could survive and multiply in sodic soils with pH as high as 10, the host plant was sensitive at this pH. It is limited by the pH effect *per se* or due to reduced energy source caused by reduction in the growth of host plants.

While studying the availability of P in salt affected soils of Uttar Pradesh, Bina Devi and Varshney (1979) noticed that available P was positively and significantly associated with soil pH and moisture. High pH of salt affected soils which might have contributed to enhanced mineralization of organic P was attributed to be the cause. The reduction in available P in the rainy season was attributed to the interference caused by enhanced concentration of various ionic species in the soils and decreased moisture status due to rapid evaporation.

Alkali soils have been reported to contain high amounts of available P, due to the presence of higher amounts of Na_2CO_3 in alkali soils. Ca-bound P [$\text{Ca}_3(\text{PO}_4)_2$], which is the predominant form of P in alkali soils, undergoes double decomposition, forming Na_3PO_4 and CaCO_3 , thereby sharply increasing the Olsen's extractable P (Chhabra *et al.*, 1981).

Arora and Sekhon (1981) studied the relationships of DTPA extractable Zn, Cu, Fe and Mn with pH, CaCO_3 , organic carbon, clay and silt in some soil series of Punjab state. The correlation studies have indicated that pH, silt and organic matter influence the extraction of these micronutrients with DTPA. The dominant influence of pH on extractable Zn and Mn suggests that DTPA extracts largely the inorganic mineral forms of these nutrients. The extraction of iron is influenced by both pH and silt particles as well as Fe-minerals. Judging from the effect of organic carbon and silt contents it becomes evident that DTPA extracts the organically complexed and easily exchangeable forms of copper held on the silt particles.

The availability of K in alkali soils has generally been reported to be adequate, the main reason being the predominance of K rich micaceous minerals in soils of arid and

semi-arid regions (Kapoor *et al.*, 1981). Also, dissolution of muscovite released large amounts of K in sodic soil environments (Pal, 1985).

Gupta and Abrol (1990a and 1990b) and Singh *et al.* (1975) observed that water soluble-P increased with alkalinity in all the major alkali benchmark soil series of the Indo-gangetic plains.

Kanthaliya and Bhatt (1991) obtained a positive but non-significant correlation between available K and organic carbon. The positive relation was attributed to release of K from organic complexes. But since the correlation was non-significant, it was concluded that organic carbon could not be used as an index of K availability in the soils investigated.

Availability of P in air dry and waterlogged conditions was compared in salt affected soils by Srivastava and Srivastava (1993) and Singh *et al.* (1969). It was noticed that in air dry soil, with the increase in pH from 7.3 to 10.8, availability of P increased linearly. The increased availability of P in soils saturated with sodium was attributed to accelerated dissolution of Ca-P compounds or complexes this is due to the creation of sink for calcium. The increase in 6.1 ppm in available P with the unit increase in soils pH was observed in air dry soils, whereas the increase in P per unit pH increase in waterlogged soils was 7.5 ppm.

Indian soils contained low to medium amounts of available phosphorus and it reduced with depth. The reduced availability in the soils investigated could be ascribed to the varying amounts of lime (CaCO_3), where by phosphorus gets fixed as calcium phosphate specially in salt affected soils, which are dominated by silt and clay sized carbonated fractions, which provides enhanced surface area for phosphorus fixation (Murthy, 1988 and Srinivasa Rao *et al.*, 1991). The available phosphorus content reduced with depth and with decrease in organic carbon was noticed by Chauhan (1995).

Srivastava and Srivastava (1993) reported that pHs poorly and negatively correlated with Ca^{2+} and Mg^{2+} ($r = 0.32^*$) whereas comparatively higher correlation were observed between pHs, Na^+ , carbonates and bicarbonates suggesting soluble Na^+ , carbonates and bicarbonates mainly impart sodic rather than saline characteristics to soils

and are highly correlated with ECe and according to regression equation pHs increased at the rate of 0.04 unit per unit increased in the ECe.

Available N ranged from 50.4 to 85.9 and from 80.3 to 105.1 kg ha⁻¹ in the Inceptisols (pH 9.5 to 10.5) and Vertisols (pH 8.6 to 9.7) of Karnataka, India, respectively. Available P varied from 4.5 to 12.0 kg ha⁻¹ in Inceptisols and from 6.5 to 13.5 kg ha⁻¹ in Vertisols. Available K ranged from 51 to 118 and 56 to 118 kg ha⁻¹ in Inceptisols and Vertisols, respectively. B varied from 0.40 to 2.92 ppm in Inceptisols, and from 0.56 to 1.93 ppm in Vertisols (Mruthunjaya and Kenchanna Gowda, 1993).

Dhane and Shukla (1995) in soils of Maharashtra and Maji *et al.* (1993) in coastal soils of Sunderbans, West Bengal recorded decreasing trends of available iron down the depth. Iron and copper were found negatively correlated with pH and positively correlated with EC and organic carbon.

In a study on distribution of available N in semi-arid region of Rajasthan, Kumawat (2000) observed that soils mostly low in clay content and low to very low in organic carbon, showed a decreasing trend of available N with depth. There was a linear relationship between organic carbon and available N, meaning the latter was found to accumulate in surface layers. Lower clay content in these soils, with pH 7.8 to 8.5 was responsible for low CEC and thus low retention of ammonium ions on exchange complex, leading to lower N availability.

Mali *et al.* (2002) studied the correlation between soil physico-chemical properties and available micronutrients in these soils and reported that iron and manganese are significantly positively correlated with organic carbon, available nitrogen and phosphorus. However, they were negatively correlated with ECe but positively correlated with soil pH, calcium carbonate and potassium, but values were not significant. Zinc and copper were negatively correlated with calcium carbonate, organic carbon, available nitrogen, phosphorus and potassium. But the 'r' values were not significant. However, the available phosphorus was significantly negatively correlated with zinc and copper.

Lakshminarayana Murthy (2003) reported that the available nitrogen in salt affected soils of southern Karnataka decreased with depth due to poor physical condition of the soil.

Sharma *et al.* (2003) studied the correlation between micronutrients vis-a-vis soil properties in some salt affected soils of Nagpur district in semi arid region of Rajasthan. Zn, Cu, Fe, Mn and B showed positive correlation with silt plus clay and organic carbon, and negative correlation with pH and calcium carbonate content.

Najar *et al.* (2005) assessed the nutrient status of some salt affected soils of Jammu and Kashmir at different locations and recorded that the contents of available N ranged from 82 to 144 kg ha⁻¹ in the surface layers and decreased with depth. The status of K was high and varied from 284 to 325 kg ha⁻¹ and exhibited a regular depth distribution pattern. Similarly zinc content varied from 0.28 to 0.44 ppm and did not exhibit a regular depth distribution.

Sharma *et al.* (2008) reported that the content of available N in salt affected soils of Amritsar district (Punjab) varied from 63 to 170 kg ha⁻¹, available P from 9.4 to 84.9 kg ha⁻¹, available K from 84 to 700 kg ha⁻¹ and available S from 24.6 to 60.0 kg ha⁻¹.

Yerriswamy *et al.* (1998) studied the nutrient status of some salt affected Vertisols of Karnataka and reported that the soils are low in available nitrogen (46.0 to 162 kg ha⁻¹), low to medium in phosphorus (2.0 to 13.0 kg ha⁻¹) and high in potassium (161 to 484 kg ha⁻¹).

Sharma *et al.* (2008) studied the spatial distribution of soil nutrient using Arc Info GIS. The maps of various nutrient elements clearly indicated the specific locales, where deficiency of nutrients constrained crop production. Multi-nutrient (NPK) map suggested that the combined NPK deficiency at a single place was negligible. Based upon the linear coefficient of correlation between macronutrients and soil properties, a significant positive correlation occurred between organic carbon and N, K and S. The available nutrients showed a negative correlation with CaCO₃.

Nayanaka *et al.* (2010) observed spatial variability of agronomically important soil properties of a paddy growing tract in Pulasthigama in Polonnaruwa district of Sri

Lanka. The coefficient of variation of properties ranged from 5% (pH) to 140% (Zn content). According to the calculated variograms, the available P, clay content and organic matter exhibited a highly spatially structured variability whereas, a medium structured variability was observed for soil pH.

The content of DTPA extractable Fe, Mn, Cu and Zn was highest in the fine textured soils having high organic carbon content. The coarse textured soils were found to be more prone to Fe, Mn, Cu, Zn and B deficiencies. Among soil properties, organic carbon, CEC and silt and clay content had a positive influence on the availability of micronutrients whereas, sand content, pH and CaCO_3 content had negative influence on availability of these micronutrients (Rajendra *et al.*, 2011).

The soils of Trans Yamuna area in Etawah district (UP) were low in available nitrogen and low to medium in available phosphorus and potassium content. Majority of the soils were low in DTPA-extractable Zn, Fe and Cu but sufficient in Mn (Verma *et al.*, 2012).

Nutrient status of profile soil samples representing semi-arid agro-ecological region of Banaganapalle mandal in Kurnool district was low to medium in available N, medium to high in available P, low to high in available K and high in available S (Geetha Sireesha and Naidu, 2013).

Vijaya Kumar *et al.* (2013) reported that salt affected soils of Ongole division, Prakasam district were low in available nitrogen (N), medium to high in available phosphorus (P) and high in available potassium (K). Soil available N had a significant and positive correlation with OC ($r = 0.71^{**}$). The soil pH had a significant and negative correlation with available Fe ($r = -0.234^*$), Mn ($r = -0.247^*$) and Cu ($r = -0.219^*$). Soils were deficient in DTPA extractable Zn and Fe, whereas, sufficient in DTPA extractable Cu and Mn.

2.5 Effect of gypsum and NPK on growth and yield of rice

The paddy yield increased significantly with increasing the dose of N fertilizer. The maximum yield (57.04 g pot^{-1}) was obtained for S0 ($\text{ECe } 6.0 \text{ dS m}^{-1} + \text{SAR } 3.22$) and minimum (27.88 g pot^{-1}) for S3 ($\text{ECe } 6.0 \text{ dS m}^{-1} + \text{SAR } 55.5$). The yield of rice increased with increasing level of N (100, 125 and 150 mg kg^{-1} soil). The reduction in yield

was attributed to nutritional imbalance and higher osmotic potential and toxicity of specific ion. While the increase in yield with increasing level of N was attributed to increase in CEC of root (Bear, 1964) and increased root growth and /or volume played a key role in inducing the tolerance against the salt stress. Similar reduction in yield of rice has been reported by Arjunan and Chandrasekaran (1998). The results are in agreement with those reported by Malik and Shah (1996) for wheat and Nadeem *et al.* (1995) for rice crop.

Sharma *et al.* (1981) reported that application of gypsum in alkali soil increased the grain yield of rice and wheat which varied from 4.0 to 4.8 and 1.7 to 2.0 t ha⁻¹ respectively during four years of reclamation.

Iqbal *et al.* (1992) studied the growth response of rice to (NH₄SO₄-N) rates in salt-affected soils of Pakistan. The N was applied @ 0, 30, 60, 90, 120 kg ha⁻¹ along with a basal dose of P and K @ 50 and 30 kg ha⁻¹. Grain and straw yield and number of productive tillers by plants increased with increasing rates of N application. Maximum productive tillers and yield of rice was recorded at 90 kg N ha⁻¹.

Srinivasa (1999) revealed that application of amendments such as pressmud and gypsum + pressmud in sodic soil with drainage increased the paddy grain yield significantly. The highest grain yield was recorded with pressmud application during 1992 and 1993 while its combination with gypsum accounted for this effect in 1994. The increase in yield with gypsum application was not significant in all the three years.

Anand Swarup and Yaduvanshi (2000) reported that continuous use of N and P fertilizers significantly enhanced the yield of rice in alkali soils. The maximum yield was obtained with 100% NPK + GM followed by 150% NPK and 100% NPK + FYM.

Yaduvanshi and Swarup (2005) reported that application of farm yard manure 10 Mg ha⁻¹, gypsum 5 Mg ha⁻¹ and pressmud 10 Mg ha⁻¹ along with NPK fertilizer significantly enhanced the yields of rice and wheat grown with sodic irrigation water over NPK alone. However continuous use of fertilizer N alone (120 kg ha⁻¹) or in combination with P and K significantly improved rice and wheat yields over control (no fertilizer).

Gypsum application in different doses (0, 25, 50, 75, 100 and 200% of the gypsum requirement) increased the yield of rice by 9.8 to 25.3% and that of wheat crop by

10-80% over control. Maximum increase occurred with the application rate of 200% of GR in both the cases (Sabir *et al.*, 2007).

Experiment conducted in recently reclaimed sodic soils to study the fertilizer requirement of wheat revealed that the grain (9.76 to 44.72%) and straw (11.30 to 56.70%) yield of wheat increased with each increment of N from 85, 130 and 175 kg ha⁻¹, whereas the increase with P and K were found non-significant, except P at higher rates and K at lower rate. On the basis of these results Mehdi *et al.* (2007) concluded that the optimum dose for wheat crop was 175, 105 and 60 kg ha⁻¹ of N, P₂O₅ and K₂O, respectively.

Field experiments conducted in recently reclaimed soils during 2001 -2003 by Mehdi *et al.*, (2008) indicated that the grain and straw yield of rice increased significantly in both rice-wheat and rice-berseem rotation due to application of fertilizers compared to control. However the highest yield was obtained where RDF + 25 per cent additional NPK was applied.

Motamed *et al.* (2008) revealed that salinity (NaCl) adversely affected yield, number of tillers per pot, filled and unfilled spikes, fertility and 100 grain weight, but increased the number of unfilled tillers of rice. The average yield loss threshold was calculated as 1.3 dS m⁻¹. On an average, the number of panicles and number of filled spikes accounted for 80 and 59% of total variation of grain yield, but it decreased by increasing salinity level. There was a high correlation between yield and number of panicle and grain weight per panicle.

Application of recommended doses of NPK (120+26+42 kg ha⁻¹) with green manuring or farm yard manure (FYM) increased the yield of rice significantly over the recommended dose of NPK alone. The mean yield was 5.44, 6.38 and 6.25 t ha⁻¹ with the application of the recommended doses of NPK alone and its combination with green manuring and FYM, respectively. Addition of organic manure along with chemical fertilizers has increased the rice yield by 16 per cent as compared to the recommended doses of NPK alone. The maximum yield of rice was obtained with green manuring treatment. Half doses of recommended NPK (60+13+21 kg ha⁻¹) with green manuring or FYM

yielded more or less equal to that of yield obtained by recommended doses of NPK (Yaduvanshi, 2009).

Suma and Savitha (2010) reported that technological interventions such as incorporation of green manure crop, application of gypsum based on soil test, growing of saline tolerant paddy variety, transplanting of 30 days aged seedlings, application of bio fertilizers and chemical fertilizers based on soil test resulted in decrease in EC from 4.67 to 3.23 dSm⁻¹ besides recording higher grain yield of paddy crop under saline soils of Cauvery command area.

A field experiment was conducted by Shahzada Munawar Mehdi *et al.* (2011) to study the effect of integrated nutrient management on yield of rice in a recently reclaimed saline sodic soil. The data showed that different combinations of organic manures with chemical fertilizers increased paddy grain and straw yield significantly over application of organic manures alone. Among different combinations, sesbania at 20 tons ha⁻¹ + 75% recommended dose (R.D.) proved to be the best combination followed by sesbania 20 tons ha⁻¹ + 50% R.D. It was also noted that sesbania green manuring alone was found superior to FYM alone.

Dinesh Sharma *et al.* (2012) reported that increasing NP levels significantly increased the crop growth parameters viz. plant height, number of tillers m⁻² and dry matter accumulation of rice (basmati cultivars) in alkali soils of Hisar, Haryana. The yield contributing characters (panicles/m², grains/panicle), yield (grain and straw), net profit and benefit cost ratio were higher with N₉₀P₄₅ kg ha⁻¹. Application of N₉₀P₄₅ kg ha⁻¹ also showed highest nitrogen and phosphorus uptake.

Lal Bahadur *et al.* (2013) studied the nutrient management in rice-wheat sequence under sodic soil condition. Results indicated that grain and straw yield and harvest index were significantly increased by the application of fertilizer on the soil test basis. The grain and straw yield further increased when 5 t ha⁻¹ organic manures (FYM, pressmud and NADEP compost) were added along with recommended doses of fertilizers which were at par with 125% STR.

2.6 Effect of gypsum and NPK on nutrient uptake of rice

At higher salinity, salt tolerant rice varieties had higher salt content and lower uptake of Na^+ and Cl^- as compared with less tolerant cultivars. Although both chloride and sulphate were the major anions in the soil, chlorides formed the bulk of inorganic ions in plant. A positive correlation was observed between salt content and dry matter yield (Bandyopadhyay *et al.*, 1985).

Results of the study conducted by Anand Swarup (1991) indicated that application of gypsum alone or in combination with FYM or green manure along with zinc significantly increased the yield and Zn, Fe and Mn concentration in rice crop.

Iqbal *et al.* (1992) studied the growth response of rice to $(\text{NH}_4\text{SO}_4\text{-N})$ rates in salt-affected soils of Pakistan. The N was applied @ 0, 30, 60, 90, 120 kg ha^{-1} along with a basal dose of P and K @ 50 and 30 kg ha^{-1} . The uptake of NPK increased with increasing rates of N. Maximum uptake of NPK was recorded in the treatment receiving 90 kg N ha^{-1} . The minimum NPK uptake was obtained in the control.

Application of NPK increased the uptake of macronutrients (N, P and K) and micronutrients (Fe, Mn, Zn, Cu) by the rice-wheat rotation (Bharadwaj *et al.*, 1994). The nutrients uptake further increased with increasing dose of NPK and addition of FYM along with 100 per cent NPK to a greater extent. They attributed it to extra amount of nutrients supplied by the FYM, besides beneficial effect of organic matter addition on the availability of soil nutrients.

Kumar *et al.* (1996) reported that increased levels of N application increased the grain and straw yield and N uptake significantly. Application of N increased N, P and Cu concentration and decreased that of K, Zn, Mn and Fe concentration in the crop.

Dhanya *et al.* (2006) revealed that the application of 150 per cent RDF, biofertilizer and ZnSO_4 @ 25 kg ha^{-1} recorded the highest uptake of N, P, K and Zn at all stages of the rice crop growth.

Application of pressmud and gypsum + pressmud with RDF (125:50:50 kg NPK ha^{-1}) under drainage conditions increased the leaf nitrogen, phosphorus and potassium

content significantly at flowering stage. But the increase was not significant in straw and grain samples at harvest (Srinivasa, 1999).

The NPK contents of both grain and straw were significantly increased over control due to application of NPK. Nitrogen concentration was increased both in grain and straw with increasing levels of N application (Mehdi *et al.*, 2007).

The results of INM in rice grown in recently reclaimed soils indicated that the NPK contents both in paddy grain and straw were increased significantly by applying various combinations of organic manures with chemical fertilizers over application of organic manures alone. Maximum contents of NPK both in paddy grain and straw of rice were recorded in the combination of sesbania at 20 ton ha⁻¹ + 75% R.D. followed by sesbania 20 ton ha⁻¹ + 50% R.D (Shahzada Munawar Mehdi *et al.*, 2011).

Nitrogen, P and K uptake by rice in sodic soil condition significantly increased by the application of 100% NPK along with Zn. However, NPK uptake further increased when 5 t ha⁻¹ organic manures (FYM, pressmud or NADEP compost) were applied @ 5 t ha⁻¹ (Lal Bahadur *et al.*, 2013).

2.7 Effect of gypsum and NPK on soil properties

Singh *et al.* (1980) studied the effect of gypsum and pyrites on the soil properties. They observed that gypsum was more effective in reducing the pH, electrical conductivity and sodium content of soils as compared to pyrite. The sodium, calcium, potassium, carbonates, bicarbonates and sulphates increased with the levels of applied gypsum in the leachate of amended soils. Both field and laboratory studies in semi-reclaimed sodic soil with different crops indicated no response to K, which could be related to enormous release of K from K-bearing minerals under sodic soil conditions (Pal and Mandal, 1980).

Chhabra *et al.* (1981) revealed that Olsen's P decreased with increase in rate of gypsum up to 100 per cent GR applied due to leaching. Under natural conditions Na₂CO₃ which is the predominant salt in sodic soils, reacts with native calcium phosphate to form highly soluble sodium phosphate which is leached during reclamation. Gypsum mixed with soil at a rate of 100 per cent GR and above decreases the leaching of phosphorus, due to immobilization of soluble P by CaSO₄ through formation of less soluble Ca-P

compounds, common ion effect to decrease the solubility of Ca-P compound and lowering of soil pH which in turn decreases the soluble P in the pH range of 8.3 to 10.

Sharma *et al.* (1981) reported that application of gypsum and growing of crops in alkali soil decreased the soil pH, electrical conductivity, calcium carbonate, exchangeable sodium, carbonates, chlorides and dispersion ratio, whereas exchangeable calcium and magnesium, hydraulic conductivity, water infiltration and redistribution increased up to a depth of 45 cm.

The application of gypsum or rice husk or FYM to submerged sodic soil during growth period of rice crop increased the available Fe, Mn, Zn and P up to 60 days but thereafter it remained either constant or declined slightly (Anand Swarup, 1982). Among the amendments, farmyard manure and rice husk resulted in marked improvement in Fe and Mn except Zn over gypsum and control. On the other hand available P behaved quite differently and decreased in the following order with crop growth: gypsum > rice husk > farmyard manure > control.

Chauhan and Tripathi (1983) reported that application of gypsum followed by leaching markedly reduced the ESP, pH and soluble boron content of soil. The change due to application of gypsum at 20 t ha⁻¹ affected the pH and ESP in the top 23cm layer only, but salt content and boron content were reduced to near normal levels up to 92 cm depth.

Anand Swarup (1991) studied the effects of gypsum with green manure and farmyard manure on nutrition of rice in a sodic soil with pH 10.2. Application of gypsum markedly decreased the pH to 9.2 after three months, while combination of gypsum with GM and FYM reduced the pH to 9.0 and reduced the ESP from 86 to 28. Rice responded significantly to zinc application in combination with gypsum.

The application of 100 per cent NPK plus FYM did not affect the electrical conductivity of soils (Subramanian and Kumaraswamy, 1989). Santhy *et al.* (1998) observed that the salt content increased slightly due to application of 100 per cent NPK in combination with farmyard manure.

Application of gypsum (50 % GR) and varied levels of P with recommended dose of N and K with zinc sulphate @ 5 kg ha⁻¹ decreased the surface soil pH from 10.3 to 8.5 with no further change afterwards. However, there was a continuous improvement in the pH or ESP of the lower soil layers as a result of rice-wheat cropping (Chhabra and Thakur, 2000).

Hebbara *et al.* (2004) reported that continuous ponding was better than intermittent leaching methods under paddy-paddy cropping sequence for reclaiming the saline soil as it decreases soil salinity and increase the paddy yield. Intermittent pondings (2 and 3 days) were superior to continuous poundings in terms of water saving and water use efficiency.

Phosphorus applied at the rate of 26 kg ha⁻¹ each to rice and wheat raised with sodic waters significantly improved the yields and led to a considerable build up in available soil P. When N alone was applied, available soil P and K declined from the initial level of 14.8 and 275 kg ha⁻¹ to 8.5 and 250 kg ha⁻¹, respectively (Yaduvanshi and Swarup, 2005).

Ahmad *et al.* (2006) reported that application of gypsum to wheat and rice crop grown in calcareous saline sodic soils removed greater amounts of sodium (Na⁺) from the root zone leaving behind minimum level of sodium adsorption ratio (SAR) and the greatest ECe: SAR ratio in post amelioration soil. Cropping treatments alone had little effect on calcite dissolution and removed less Na⁺ during one year period.

The conjoint use of FeSO₄, ZnSO₄, FYM and *Thiobacillus ferrooxidans* significantly increased the DTPA-Zn and Fe in the saline-sodic soil (Jagtap *et al.*, 2006). The application of micronutrient fertilizers had pronounced effect on release of ammonical and nitrate nitrogen and available phosphorus in the soil. The effect was more pronounced when these micronutrients were applied along with the FYM (Jagtap *et al.*, 2007).

Mehdi *et al.* (2007) reported that application of NPK to recently reclaimed sodic soils using gypsum decreased the soil salinity and sodicity, while fertility status of soil was improved due to reclamation and application of NPK.

Application of elemental sulphur in an alkaline soil increased the solubilization of anions and cations and enhanced its salt leaching (Jose Gerardo *et al.*, 2007). It also increased the electrical conductivity and decreased the pH as compared to unamended control soil.

Sabir *et al.* (2007) reported that application of gypsum at 0, 25, 50, 75, 100 and 200% of the gypsum requirement to salt affected soil under rice - wheat cropping decreased the pH, EC and SAR of the leachate samples with increasing level of gypsum and with the number of leachate. EC and SAR decreased considerably relative to pH. The data further indicated that soils were also improved with gypsum application especially with respect to pH and SAR.

Addition of compost with and without chemical fertilizer for rice and wheat increased the crop yields and improved the soil conditions (Sarwar *et al.*, 2008). The soil pHs was lowered and SAR decreased due to acidic effect of compost, formation of acids, release of Ca and leaching of Na. There was a slight increase in ECe of the soil. The available amount of all the major plant nutrients (N, P, K, Ca and Mg) and organic matter content increased in the soil.

Combined use of organic amendments, bioinoculants and gypsum brought about significant differences in soil pH, EC, ESP and organic carbon (Trilok Nath Rai *et al.*, 2010). The maximum reduction in chemical properties like soil reaction and EC were recorded in the treatment receiving water hyacinth compost @ 10 t ha⁻¹ + 25% GR + bioinoculants.

Joachim and Hubert (2010) studied the effect of gypsum and placement methods on the physical and chemical properties of a saline soil during reclamation process by leaching under natural rainfall. Results showed that incorporating gypsum decreased the exch. Na, ECe, SAR, ESP and improved the available water capacity of soil.

Sharma *et al.* (2011) studied the effect of gypsum application and growing crops on an alkali soil. Effect of four years of reclamation showed that there was reduction in pH, ECe, exchangeable sodium, dispersion ratio and calcium carbonate content. There was increase in hydraulic conductivity, exchangeable calcium plus magnesium, water in-

filtration and redistribution. The soil pH (1:2) reduced from 10.4 to 8.4 and EC (1:2) from 1.62 to 0.28 dSm⁻¹ in the surface layers within 4 years of reclamation.

Mohamed and Abdel-Fattah (2012) studied the efficiency of gypsum, rice straw compost and their different combinations on reclamation of clay saline-sodic soils. The results indicated that all the amendments used either, singly or in combination decreased the EC, pH, SAR, and ESP markedly compared to control. The results also showed that combined application were more efficient than individual application. Increase in the rate of gypsum used leads to an increase in decrease of salinity as well as sodicity.

Mahmoodabadi *et al.* (2013) reported that the effect of application of sulphuric acid in irrigation water to calcareous saline-sodic soil was negligible on soil EC, but was significant on soil SAR. The monovalent cations concentrations, soil EC and SAR were lower in the surface layer and increased with depth. However no changes with depth were found for the bivalent cations suggesting Na⁺ and K⁺ higher mobility than Ca²⁺ and Mg²⁺ with in the soil profile.

III. MATERIAL AND METHODS

Field experiments were conducted during *Kharif* 2013 and summer 2014 to study the effect of nutrients levels and ratios on growth and yield of rice in gypsum amended sodic soil at 'B' block of Zonal Agricultural Research Station (ZARS), Vishweshawaraiah Canal (VC) Farm, Mandya. Besides, characterization of salt affected soils, in selected locations of Cauvery Command Area (CCA) was carried out. In order to study the characters of salt affected soils, samples were collected from surface, subsurface and horizon wise in the profiles from identified locations. The details regarding location of sampling sites, collection of soil and analytical methods employed in the characterization as well as the methodology followed in the field experiments and analytical methods employed during the course of soil and plant analysis are presented in this chapter under different headings.

3.1 Identification of salt affected fields

Four locations (sites) were identified for characterization of salt affected soils in consultation with soil scientists of ZARS, V.C. Farm, Mandya, Krishi Vignana Kendra (KVK), Hardanahalli, Chamarajanagara, Officers of Karnataka State Department of Agriculture (KSDA), Mandya and Mysuru. The identified sites were observed and finalized after physical examination of sites. On the basis of morphological characters the following four sites were selected. The location of the study area is presented in Fig. 1.

3.2 Description of the study area

3.2.1 Site 1

The study site 1 (B block) is situated at Zonal Agricultural Research Station farm (ZARS), Mandya, which falls in the southern dry zone (zone 6) of Karnataka. It lies between 76°82'01" to 76°82'08" E longitude and 12°57'03" to 12°57'05" N latitude with an average elevation of 699-715 m above MSL. Total area of the study is 8.50 ha. This area is under canal irrigation. Rice is the major crop of the area in *Kharif* season followed by rice, ragi, pulses and oilseeds, green manure, pulse or green manure during *Rabi* season.

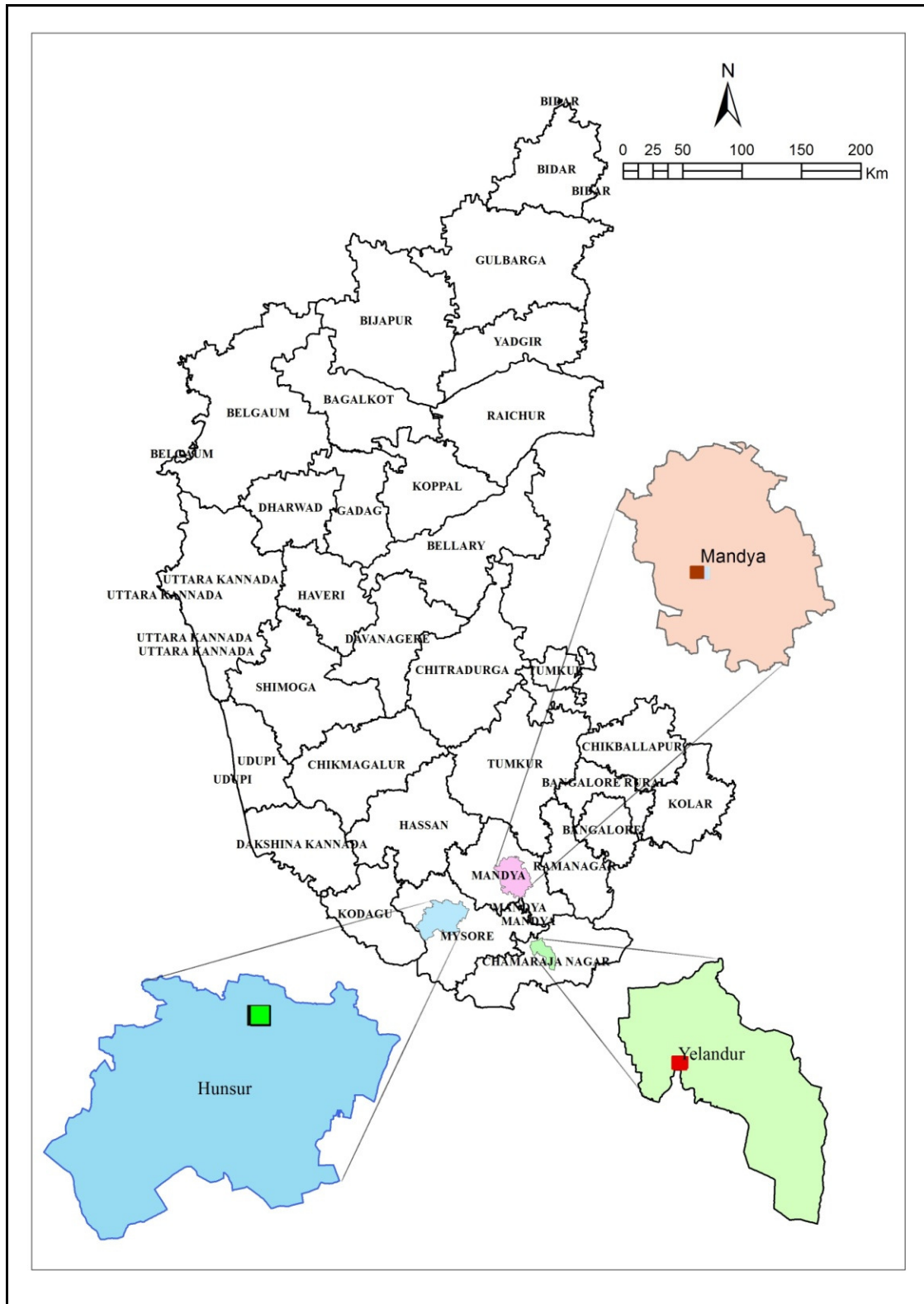


Fig.1: Location map of the study area.

3.2.2 Site 2

The study site 2 (D block) is also situated at Zonal Agricultural Research Station Farm, Mandya, which falls in the southern dry zone (zone 6). It lies between 76°82'12" to 76°82'21" E longitude and 12°57'04" to 12°57'06" N latitude with an average elevation of 705-714 m above MSL. Total area of the study is 7.60 ha. The study site was left fallow without cultivation. Eucalyptus, Acacia and Typha are the vegetation types found in the study site.

3.2.3 Site 3

The study site 3 is located at Ullala village of Hunsur taluk, Mysuru district, which falls in the southern transition zone (zone 7). It lies between 76°35'01" to 76°35'21" E longitude and 12°37'09" to 12°38'01" N latitude with an average elevation of 774-782 m above MSL. Total area of the study is 14.10 ha. Rice is the major crop of the area followed by maize, ragi and pulse crops during late *Kharif* or summer.

3.2.4 Site 4

The study site 4 is located at Upenmole village of Yelandur taluk, Chamarajanagara district, which falls in the southern dry zone (zone 6). It lies between 77°04'04" to 77°04'06" E longitude and 12°03'07" to 12°03'09" N latitude with an average elevation of 661-674 m above MSL. Total area of the study is 13.70 ha. Rice is a major crop of the area followed by pulses in the late summer.

3.3 Collection of soil sample

From all the four sites a total of one sixty surface (0-15 cm) and equal number of subsurface (15-30 cm) soil samples were collected randomly at an approximate intersection of 50 m x 50 m square grid. Soil samples were collected using core sampler. Four sub soil samples were collected along with the geo-reference point to obtain one composite sample at each sampling spot (Fig. 2a and 2b). The same method was followed at all the spots. The sub surface samples were collected in the same spot where surface samples were obtained. Similarly, soil profiles were excavated in each of the identified location. The number of profiles in each site depends upon the land form and

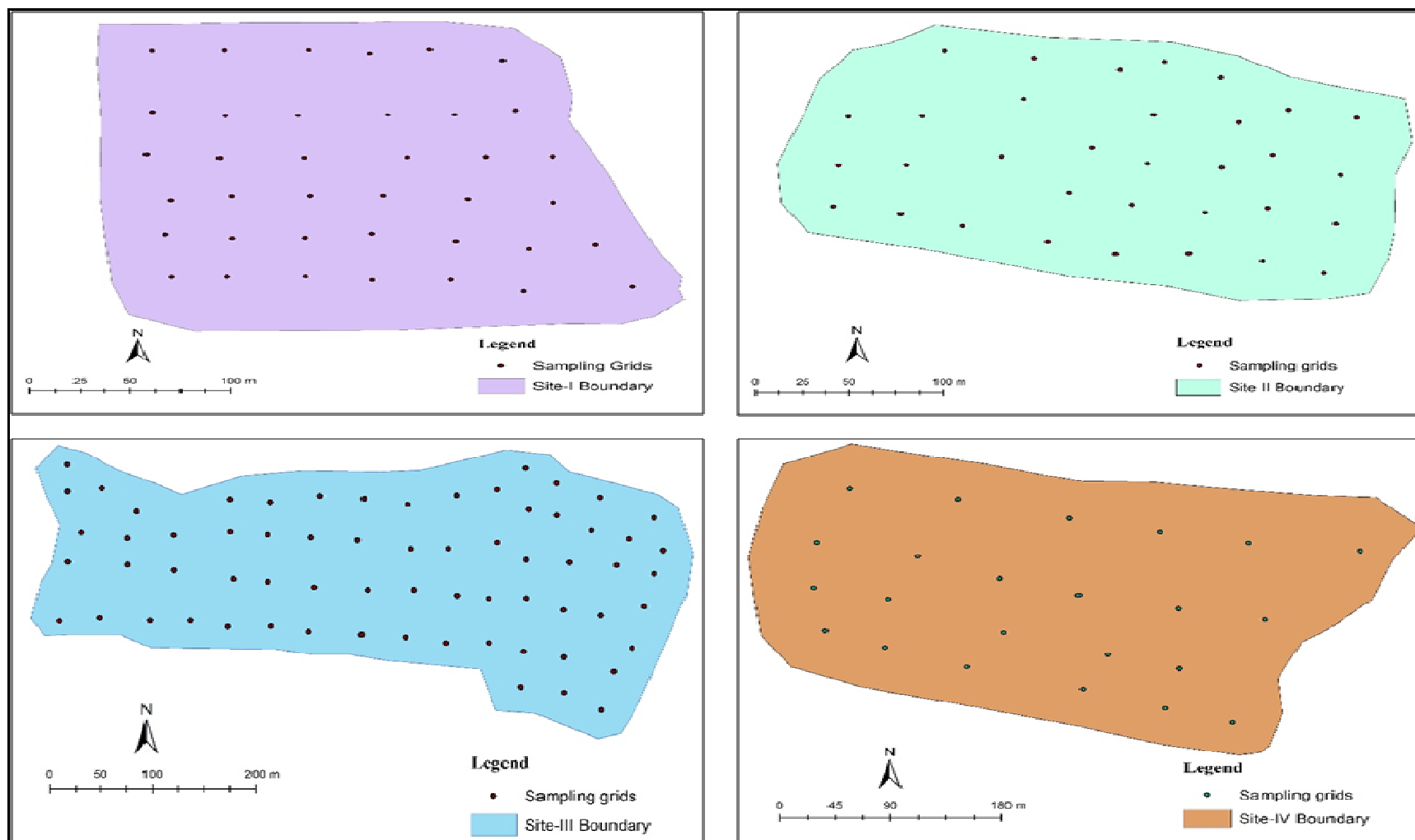


Fig. 2a: Sampling maps of site 1, site 2, site 3 and site 4 produced by ordinary kriging.

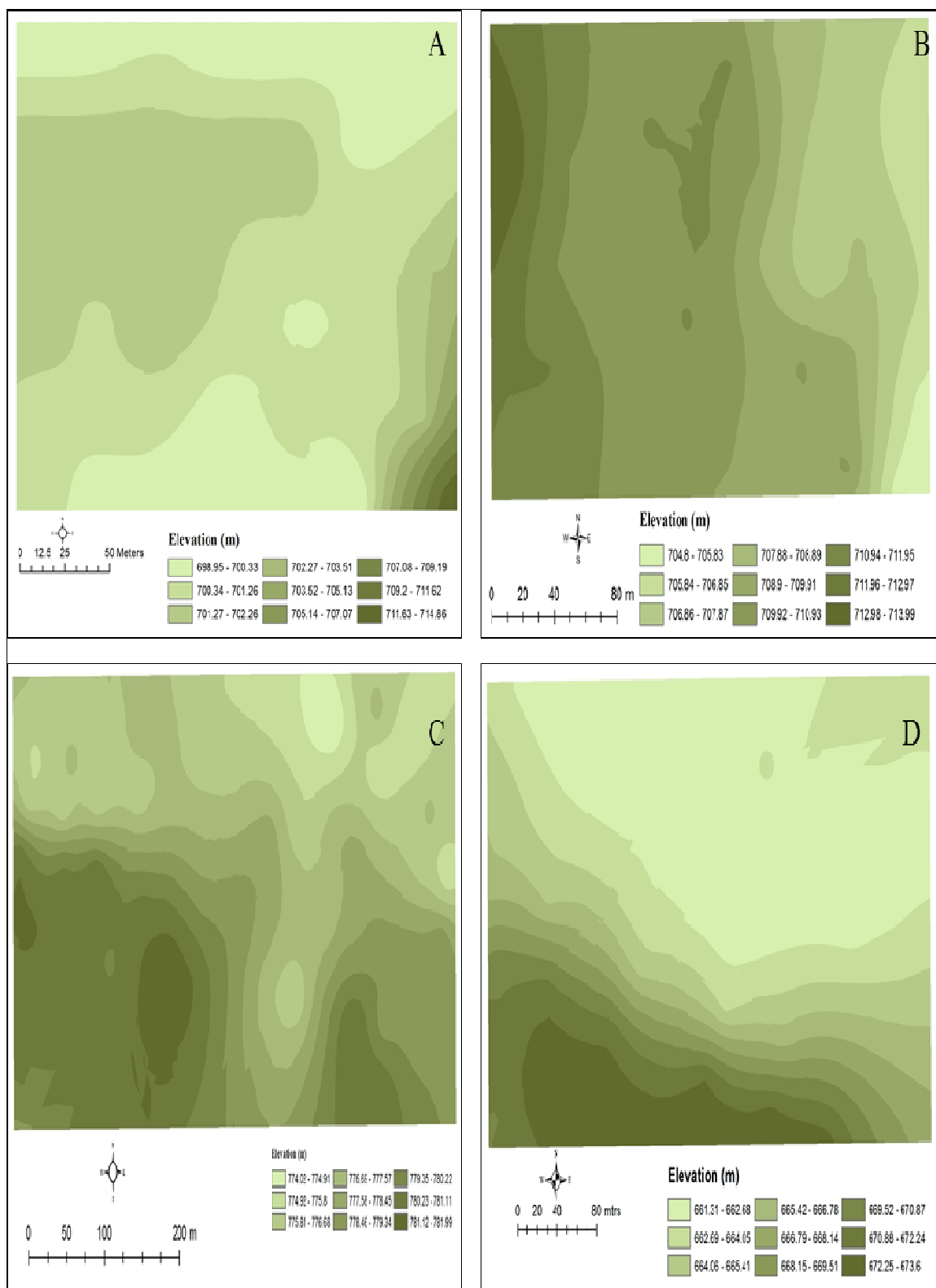


Fig. 2b: Elevation maps of site 1 (A), site 2 (B), site 3 (C) and site 4 (D) produced by ordinary krigging.

geographical area. The soil samples were collected horizon wise from each profile for physico-chemical characterization (Plate 1 and 2). The number of surface and subsurface samples collected from each site and the number of profiles excavated for characterization are given in Table 3.1.

Table 3.1: Number of surface and subsurface soil samples collected and the number of profiles excavated in each site.

Site No.	Name of the site	Number of surface samples	Number of subsurface samples	Number of profiles excavated	Area covered (ha)
1	B block	38	38	2 (P ₁ and P ₂)	8.50
2	D block	33	33	2 (P ₃ and P ₄)	7.60
3	Ulalla	66	66	3 (P ₅ , P ₆ and P ₇)	14.10
4	Upemole	23	23	4 (P ₈ , P ₉ , P ₁₀ and P ₁₁)	13.70
	Total	160	160	11	43.90

3.3.1 Preparation of soil samples

All the soil samples collected from the study sites were dried under shade, mixed thoroughly and gently ground with wooden pestle and mortar without breaking the primary particles and passed through 2 mm sieve. The 2 mm sieved samples were thoroughly mixed and preserved for further analysis.

3.4 Soil analysis

The surface and subsurface samples were analyzed for pH, electrical conductivity of saturation extract (ECe), cation exchange capacity, exchangeable Ca, Mg, K and Na, organic carbon, available nutrients status (N, P, K, S, Fe, Mn, Cu, Zn and B) and water soluble ions. In addition to the above parameters the profile samples were also analysed for particle size distribution, bulk density, water holding capacity and free calcium

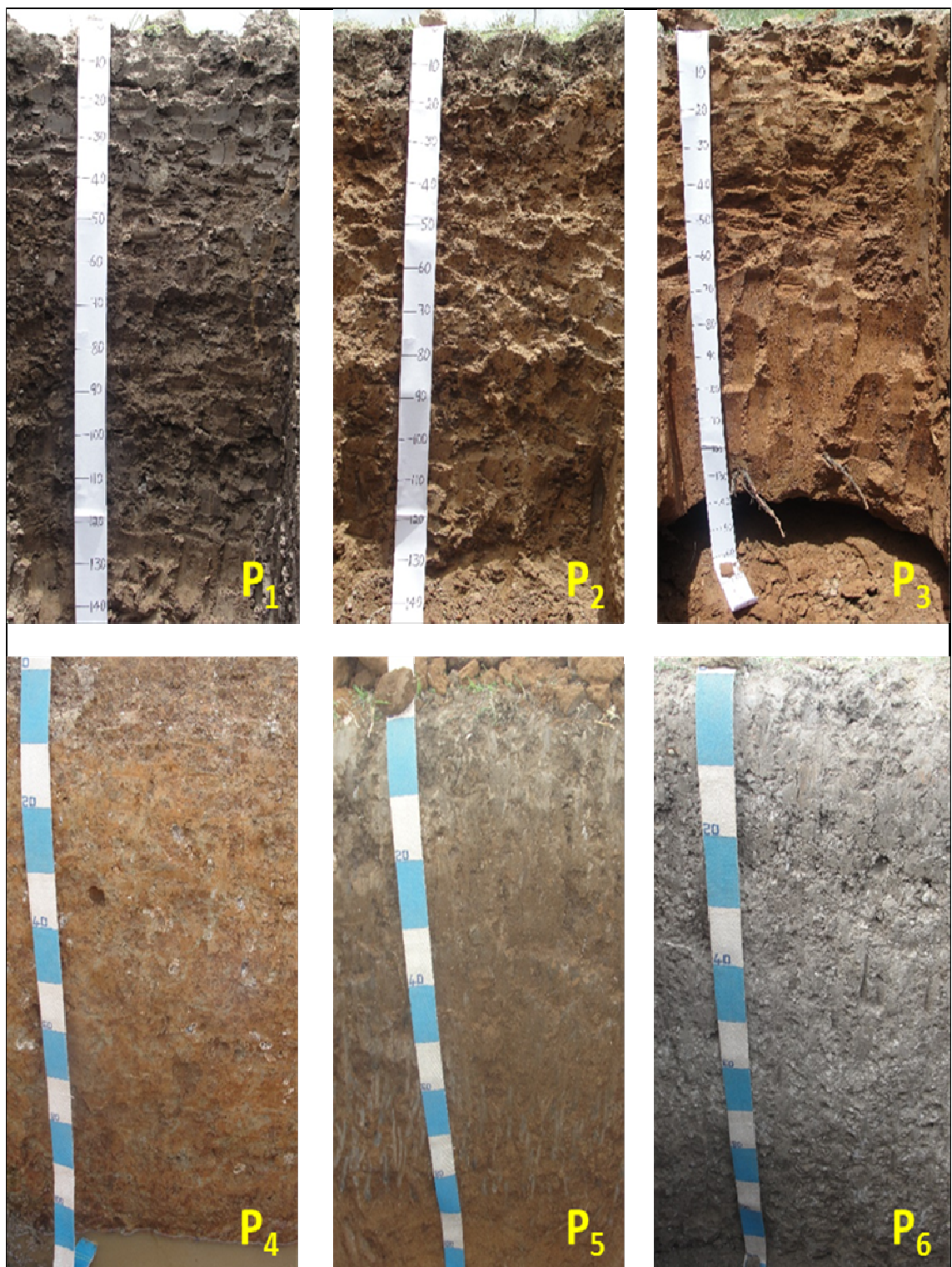


Plate 1: Soil profiles of study site 1, 2 and 3.

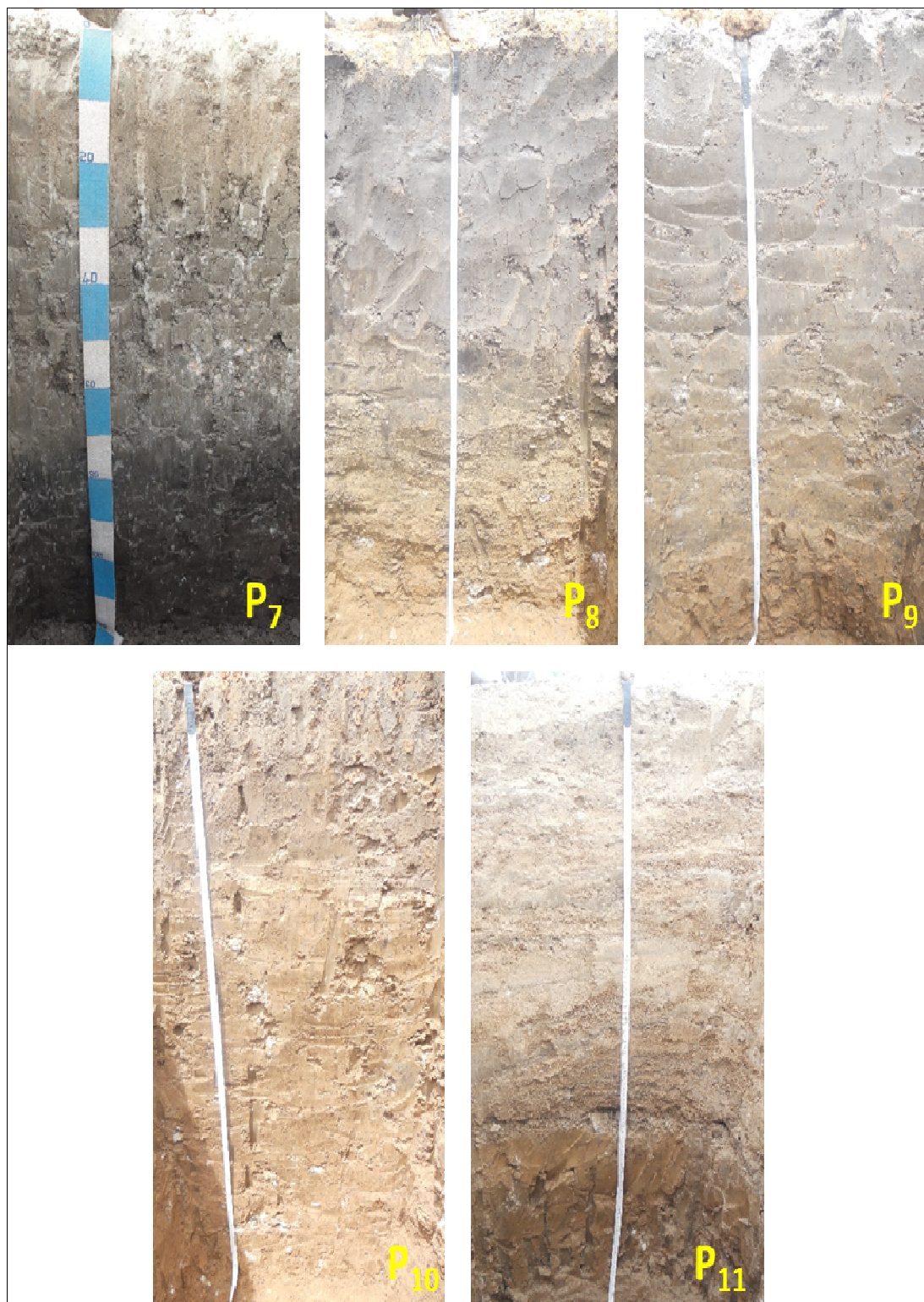


Plate 2: Soil profiles of study site 3 and 4.

carbonate content. The procedures adopted for analysis of soil samples are detailed below. Using the appropriate parameter, ESP, ratios (Ca: Mg and Ca: Na) and Electrochemical Stability Index (ESI) were also calculated.

3.4.1 Soil pH

Soil pH was determined in 1:2.5 soil:water suspension using digital pH meter (Systronics make digital pH meter 362) having glass electrode as described by Jackson (1973).

3.4.2 Electrical conductivity of saturation extract

For determination of electrical conductivity of the saturation extract (ECe), the saturated soil paste was prepared by adding distilled water to soil (250 g) while stirring with a spatula. The soil-water mixture was consolidated from time to time during the stirring process by tapping the container on the working table. The stirring was done up to saturation (at saturation the soil paste glistens as it reflects light, flows slightly when the container is held in slanting position and the paste slides freely). After one hour, the soil paste was transferred to Buchner funnel connected to the suction pump to obtain saturation extract and EC of the extract was measured using conductivity bridge (Systronics make digital EC meter 308) and results were expressed in terms of dS m^{-1} at 25°C (Jackson, 1973).

3.4.3 Exchangeable calcium and magnesium

Exchangeable Ca and Mg were extracted from soils using neutral *N* ammonium acetate at 1:5 soil to extractant ratio. The concentrations of Ca and Mg in the extract were determined by EDTA titration method as outlined by Jackson (1973).

3.4.4 Exchangeable potassium and sodium

Exchangeable K and Na were extracted from soils using neutral *N* ammonium acetate at 1:5 soil to extractant ratio. The concentrations of K and Na in the extract were determined by using a flame photometer model Elico CL- 361 outlined by Jackson (1973).

3.4.5 Cation exchange capacity

The cation exchange capacity of soils was determined by leaching the soil with sodium acetate buffered to pH 8.5 and then replacing sodium from sodium saturated soils with ammonium by leaching with neutral normal ammonium acetate after removing the unadsorbed Na by leaching with ethyl alcohol. The exchangeable sodium in the leachate was determined by using digital flame photometer model Elico CL 361 and values were expressed as $\text{cmol (p}^+) \text{ kg}^{-1} \text{ soil}$ (Richards, 1954).

3.4.6 Exchangeable sodium percentage

The exchangeable sodium percentage was calculated by using exchangeable sodium and cation exchange capacity values of soils.

$$\text{ESP} = \frac{\text{Exchangeable sodium}}{\text{Cation exchange capacity}} \times 100$$

3.4.7 Ca: Mg ratio

The calcium to magnesium ratio was calculated by using exchangeable calcium and exchangeable magnesium values of soils.

$$\text{Ca: Mg} = \frac{\text{Exchangeable calcium}}{\text{Exchangeable magnesium}}$$

3.4.8 Ca: Na ratio

The calcium to sodium ratio was calculated by using exchangeable calcium and exchangeable sodium values of soils.

$$\text{Ca: Na} = \frac{\text{Exchangeable calcium}}{\text{Exchangeable sodium}}$$

3.4.9 Electrochemical Stability Index

The electrochemical stability index (ESI) was calculated by using electrical conductivity and exchangeable sodium percentage values of soils (Mckenzie, 1998).

$$\text{ESI} = \frac{\text{Electrical conductivity (dS m}^{-1}\text{)}}{\text{ESP (\%)}}$$

3.4.10 Organic carbon

For the estimation of soil organic carbon, 1 g of 2 mm sieved soil sample was pound using agate pestle and mortar so that the entire amount passed through 0.2 mm sieve. A known weight (0.5 g) of 0.2 mm sieved soil was treated with a known excess volume of chromic acid ($\text{K}_2\text{Cr}_2\text{O}_7 + \text{H}_2\text{SO}_4$). After the oxidation of organic carbon, the unreacted $\text{K}_2\text{Cr}_2\text{O}_7$ was back titrated against standard ferrous ammonium sulphate using ferroin indicator (Walkley and Black, 1934).

3.4.11 Available nitrogen

Available nitrogen in soil was determined by alkaline potassium permanganate distillation method as described by Subbiah and Asija (1956).

3.4.12 Available phosphorus

Available phosphorus content of soil was extracted using Olsen's extractant and the concentration of phosphorus in the extract was determined by Ascorbic acid method (Jackson, 1973).

3.4.13 Available potassium

Available potassium was extracted from soil using neutral *N* ammonium acetate at 1:5 soil to extractant ratio and the concentration of potassium in the extract was determined by flame photometer Elico CL-361 (Jackson, 1973).

3.4.14 Available sulphur

Available sulphur was extracted from soil using 0.15% calcium chloride solution at 1:2.5 soil to extractant ratio. The concentration of sulphur was determined turbidimetrically as described by Page *et al.* (1982).

3.4.15 DTPA - Extractable micronutrients

Micronutrient cations (Fe, Mn, Zn and Cu) from soil were extracted with DTPA-extractant (0.005 M Diethylene Triamine Penta Acetic acid + 0.01 M CaCl_2 + 0.1 M Triethanolamine) with pH 7.3 at 1:2 soil to extractant ratio as described by Lindsay and Norvell (1978). The concentration of these cations was determined by atomic absorption spectrophotometer (AAS-Analyst 700) under suitable measuring conditions (Page *et al.*, 1982).

3.4.16 Hot water extractable boron in soil

Soil was boiled with water at 1:2 soil to water ratio for 5 minutes using reflux condenser and filtered. The boron content in the filtrate was determined by Azomethine-H reagent method using continuous flow analyzer (John *et al.*, 1975).

3.4.17 Soluble ions

The water soluble ions were extracted using distilled water (1:2 soil: water extract) as described by Richards (1954). Using suitable aliquot following water soluble cations and anions were analysed in the extracts.

3.4.17.1 Soluble cations

The water soluble cations analysed were calcium, magnesium, sodium and potassium as described by Richards (1954).

i. Calcium plus magnesium:

Calcium + magnesium were determined by complexometric titration with standard ethylene diamine tetra acetic acid (EDTA) in presence of ammonium chloride-ammonium hydroxide buffer and Erichrome black T indicator.

ii. Calcium:

Calcium was determined by titrating against standard EDTA, by making it distinctly alkaline using NaOH and in presence of Patton and Reeder's indicator (Richards, 1954).

iii. Magnesium:

The difference of (i) and (ii) was taken as magnesium.

iv. Sodium and potassium:

Water soluble sodium and potassium were determined in the soil water extracts by using a flame photometer model Elico CL- 361 (Jackson, 1973).

3.4.17.2 Soluble anions

The water soluble anions determined were carbonates, bicarbonates, chlorides and sulphates.

i. Carbonates and bicarbonates:

The carbonates and bicarbonates in the water extract of the soil were determined by titrating the extract against standard sulphuric acid using phenolphthalein as indicator for carbonate estimation and methyl orange as indicator for bicarbonate estimation (Richards, 1954).

ii. Chloride:

Chlorides were determined in the soil water extracts by titrating the extract against standard silver nitrate solution using potassium chromate as indicator (Richards, 1954).

iii. Sulphates:

The sulphates were determined turbidimetrically by precipitating sulphates as barium sulphate using barium chloride and the turbidity developed was measured using T80 UV/VIS spectrophotometer at 420 nm wavelength (Black, 1965).

3.4.18 Particle size distribution

The international pipette method was followed using sodium hexa-meta phosphate solution as dispersing agent to determine the relative proportion of the soil separates (sand, silt and clay) as described by Piper (1966).

3.4.19 Bulk density

Bulk density of profile soil samples was determined by core sampler method as described by Piper (1966) and expressed in Mg m^{-3}

3.4.20 Water holding capacity (WHC)

The water holding capacity of soil was determined by Keen Raczkowski cup method as described by Piper (1966) and expressed in per cent.

3.4.21 Alkaline earth carbonates

Free calcium carbonate content of soil was determined by acid neutralization method using standard hydrochloric acid as described by Richards (1954).

3.4.22 Gypsum requirement

Schoonovers method was used for estimation of gypsum requirement of soil (Baruah and Barthakur, 1999). Five gm of soil was shaken with 100 ml of saturated filtered solution of gypsum and filtered. 5 ml of aliquot was diluted to 25 ml using distilled water. 5 ml of $\text{NH}_4\text{Cl-NH}_4\text{OH}$ buffer and 3-4 drops of EBT indicator were added and titrated against standard EDTA solution until the colour change from wine red to blue. From the titer value the gypsum requirement of soil was calculated.

3.5 Field Experiment

3.5.1 Experimental location

The field experiment was conducted in B block of ZARS, V.C. farm, Mandya, during *Kharif* 2013 and summer 2014. The experimental location falls under southern dry

zone (Zone-6) of Karnataka and lies in 76°82'05" E longitude and 12°57'03" N latitude with an average of 705 meters above mean sea level.

3.5.2 Climatic conditions

The monthly meteorological data recorded at Zonal Agriculture Research Station, V.C. farm, Mandya, for the period from January 2013 to July 2014 regarding normal, actual and deviation in weather parameters with respect to mean monthly rainfall, maximum and minimum temperatures, I and II hour relative humidity are presented in Tables 3.2 and 3.3.

3.5.3 Normal climatic condition

The normal annual rainfall of the station during 2013 was 719 mm. The major portion of it was received during April to November with two peaks in the months of September (150.8 mm) and October (145.9 mm). The mean maximum air temperature ranged from 26.2 °C to 31.7 °C and mean minimum air temperature ranged from 14.0 °C to 19.4 °C. The highest mean maximum temperature was observed during March (31.7 °C). Lowest mean minimum temperature was observed during January (14.0 °C).

The mean monthly I and II hour (maximum and minimum) relative humidity ranged from 78 and 38 per cent in April to 86 and 54 per cent in October, respectively.

The normal annual rainfall of the station during 2014 (up to July) was 272.5 mm. The major portion of it was received during April to July with a peak value in the months of May (90.9 mm). The mean maximum air temperature ranges from 27.8 °C to 31.8 °C and mean minimum air temperature ranged from 14.0 °C to 19.4 °C. The highest mean maximum temperature was recorded during March (31.8 °C) followed by April (31.0 °C). Lowest mean minimum temperature was observed during January (14.0 °C).

The mean monthly I and II hour relative humidity ranged from 81.0 and 35.0 per cent in March to 84.0 and 55.0 per cent in July, respectively.

Table 3.2: Meteorological data indicating monthly normal, actual and deviation during 2013 at ZARS, V.C. Farm, Mandya.

Month	Total rainfall (mm)			Mean air temperature ($^{\circ}\text{C}$)						Mean relative humidity (%)					
				Maximum			Minimum			Maximum			Minimum		
	N	A	D	N	A	D	N	A	D	N	A	D	N	A	D
Jan	1.5	0.0	-1.5	29.3	27.6	-1.7	14.0	13.1	-0.9	84	84	0	39	39	0
Feb	4.4	0.0	-4.4	29.9	28.7	-1.2	15.4	13.4	-2.0	82	82	0	37	35	-2
Mar	15.2	0.0	-15.2	31.7	35.0	3.3	17.8	16.9	-0.9	81	89	8	35	51	16
Apr	51.4	65.4	14.0	30.9	35.9	5.0	19.4	20.3	0.9	78	85	7	38	47	9
May	90.6	101.4	10.8	30.1	34.4	4.3	18.9	20.4	1.5	78	86	8	40	46	6
Jun	57.2	10.3	-46.9	27.8	29.9	2.1	18.5	19.3	0.8	79	87	8	48	54	6
July	53.6	36.2	-17.4	27.8	29.2	1.4	18.9	19.2	0.3	84	88	4	55	62	7
Aug	72.4	21.7	-50.7	28.2	29.4	1.2	18.9	19.3	0.4	84	90	6	55	57	2
Sep	150.8	186.8	36.0	28.3	29.7	1.4	18.9	19.0	0.1	84	89	5	53	59	6
Oct	145.9	116.0	-29.9	28.1	29.8	1.7	18.6	18.5	-0.1	86	90	4	54	55	1
Nov	53.3	56.4	3.1	26.6	29.1	2.5	16.4	16.6	0.2	81	90	9	48	56	8
Dec	14.4	1.4	-13.0	26.2	27.9	1.7	14.2	12.5	-1.7	80	88	8	41	49	8
Total	719.0	595.6	-	-	-	-	-	-	-	-	-	-	-	-	-

N: Normal,

A: Actual,

D: Deviation from normal,

Normal values are average of 39 years (1973-2012)

Table 3.3: Meteorological data indicating monthly normal, actual and deviation during 2014 at ZARS, V.C. Farm, Mandya.

Month	Total rainfall (mm)			Mean air temperature (⁰ C)						Mean relative humidity (%)					
				Maximum			Minimum			Maximum			Minimum		
	N	A	D	N	A	D	N	A	D	N	A	D	N	A	D
Jan	1.5	0.0	-1.5	29.3	29.3	0.0	14.0	13.0	-1.0	84	89	5	39	46	7
Feb	4.3	0.8	-3.5	29.9	31.5	1.6	15.4	15.6	0.2	82	86	4	37	36	-1
Mar	14.8	36.0	21.2	31.8	32.5	0.7	17.8	15.0	-2.8	81	83	2	35	39	4
Apr	51.8	20.2	-31.6	31.0	34.2	3.2	19.4	19.3	-0.1	78	84	6	38	34	-4
May	90.9	242.5	151.6	30.2	33.6	3.4	18.9	19.9	1.0	78	89	11	40	39	-1
Jun	56.0	53.0	-3.0	27.9	32.5	4.6	18.5	19.1	0.6	79	90	11	48	36	-12
July	53.2	72.3	19.1	27.8	30.4	2.6	18.9	18.6	-0.3	84	88	4	55	45	-10
Total	272.5	424.8	-	-	-	-	-	-	-	-	-	-	-	-	-

N: Normal,

A: Actual,

D: Deviation from normal,

Normal values are average of 40 years (1973-2013)

3.5.4 Actual weather conditions during the period of experimentation

The total annual rainfall was less during 2013 (595.6 mm) and it was more during 2014 (424.8 mm) as compared to normal rainfall. During the crop growth period, September 2013 and May 2014 months recorded higher rainfall (186.8 and 242.5 mm, respectively) and was more as compared to normal annual rainfall.

The mean maximum air temperature was higher in the month of November (29.1 °C) during 2013 and April (34.2 °C), May (33.6 °C) and June (32.5 °C) during 2014. The mean minimum temperature was more than normal for most of the months. The mean monthly maximum relative humidity was 90.0 per cent in August, October, November 2013 and June 2014. The mean monthly minimum relative humidity varied, and it was more than normal in March (4 per cent) and less than the normal in April (-4 per cent) and June (-12 per cent) 2014.

3.5.5 Soil characteristics of experimental site

Before initiation of the experiment, two composite soil samples were collected from the experimental site at 0-15 cm and 15-30 cm depth. The soil samples were air dried, powdered and sieved through 2 mm sieve and analyzed for physico-chemical properties following standard procedures as described above. The soil was sandy clay loam in texture, alkaline in reaction with a pH of 8.6, ECe of 2.4 dS m⁻¹ and ESP of 31.8 per cent. The gypsum requirement was estimated for gypsum application. Soil properties of the experimental plot are given in Table 3.4.

3.5.6 Reclamation of sodic soil using gypsum

Calculated quantity of gypsum was applied to the experimental plot one month before planting and mixed by ploughing. The field selected for experiment was impounded with good quality water for two days and the water was allowed to drain to leach the soluble salts. This process was continued for 12 days.

Table 3.4: Initial properties of soil of the experimental site at ZARS, V.C. Farm, Mandya.

Parameters	0-15 cm	15-30 cm
Sand (%)	64.2	61.3
Silt (%)	11.5	10.8
Clay (%)	24.1	27.5
Textural Class	Sandy clay loam	Sandy clay loam
CEC [c mol (p ⁺) kg ⁻¹]	12.9	15.6
pH (1:2)	8.6	9.1
ECe (dS m ⁻¹)	2.4	3.2
Organic Carbon (g kg ⁻¹)	3.1	3.8
Available N (kg ha ⁻¹)	228.6	196.6
Available P ₂ O ₅ (kg ha ⁻¹)	25.3	27.4
Available K ₂ O (kg ha ⁻¹)	159.9	165.2
Exchangeable Ca [c mol (p ⁺) kg ⁻¹]	4.8	7.4
Exchangeable Mg [c mol (p ⁺) kg ⁻¹]	3.6	3.9
Exchangeable Na [cmol (p ⁺) kg ⁻¹]	4.1	3.2
ESP (%)	31.8	20.5
Available sulphur (mg kg ⁻¹)	29.6	23.8
DTPA-Fe (mg kg ⁻¹)	12.9	13.5
DTPA-Mn (mg kg ⁻¹)	10.7	12.4
DTPA-Cu (mg kg ⁻¹)	2.1	2.5
DTPA-Zn (mg kg ⁻¹)	3.2	2.6
Hot water soluble boron (mg kg ⁻¹)	0.3	0.2
Gypsum requirement (t ha ⁻¹)	34.4	-

3.6 Experimental details

3.6.1 Design and layout

The experiment was laid out in Randomized Complete Block Design (RCBD). After last leaching FYM @ 10 t ha⁻¹ was applied and mixed by puddling soil. The plots (4m x 3m) were laid out taking due care for providing channels for irrigation wherever necessary and also to remove excess water from the field. Drainage was provided between each replication (surface drains of 60 cm depth and 30 cm width channels were excavated in between each replication) to leach out salts. The treatments were replicated thrice. The plan of layout of the experiment is depicted in Fig.3. The field experiments were carried out continuously with rice-rice sequence without disturbing the plots for two seasons (Plate 3).

The experiment was conducted during *Kharif* 2013 and summer 2014. The experimental details are as follows;

Crop	: Rice
Variety	: IR-30864
Gross plot size	: 4.0 m x 3.0 m
Spacing	: 20 cm x 10 cm
Season	: <i>Kharif</i> -2013 and Summer-2014

3.6.2 IR-30864: IR-30864 is a semi-dwarf variety of rice with long slender grains. This is a high yielding and saline tolerant variety, recommended for saline and alkali soils in Karnataka.

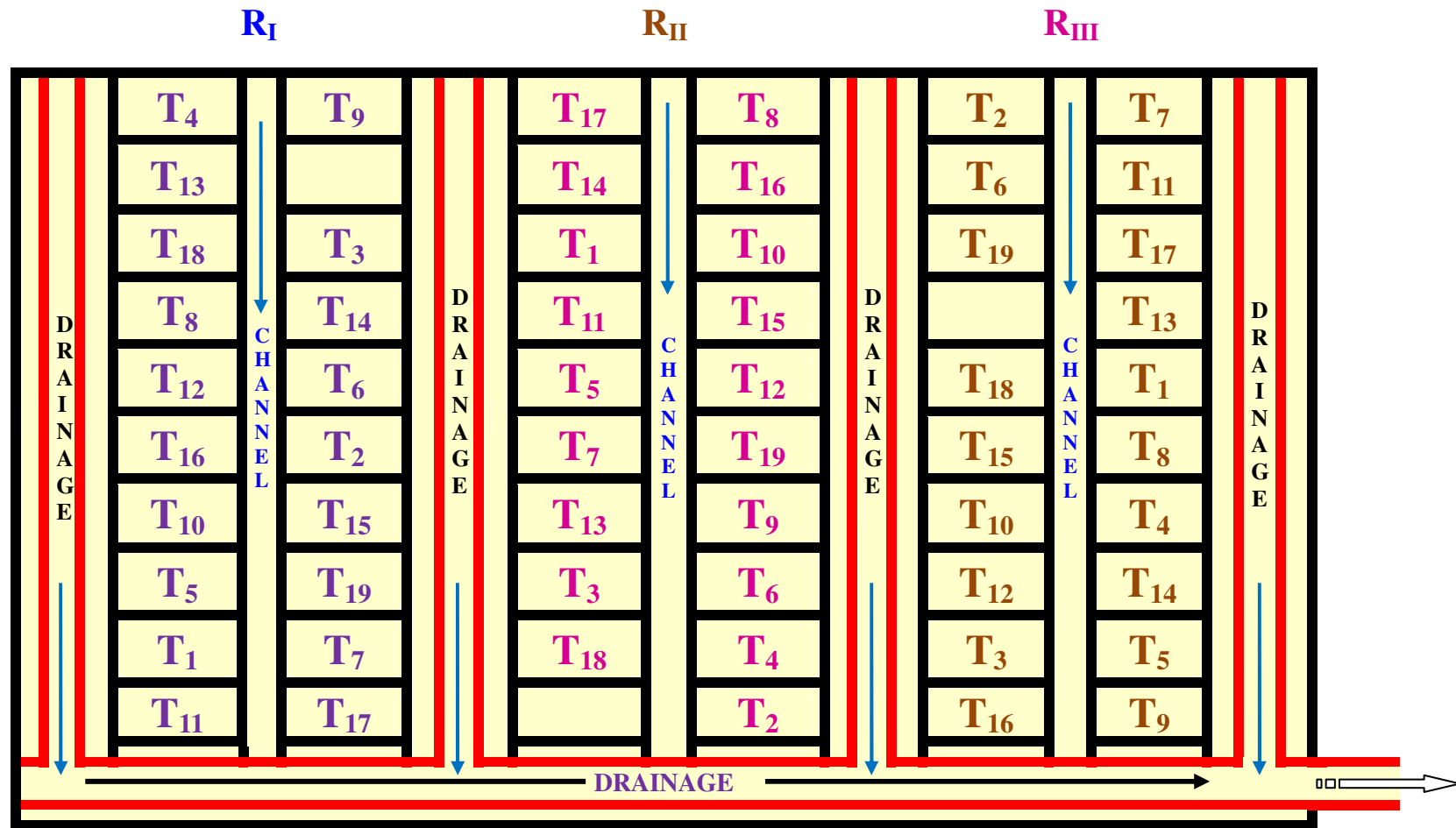


Fig. 3: Plan and layout of the field experiment.

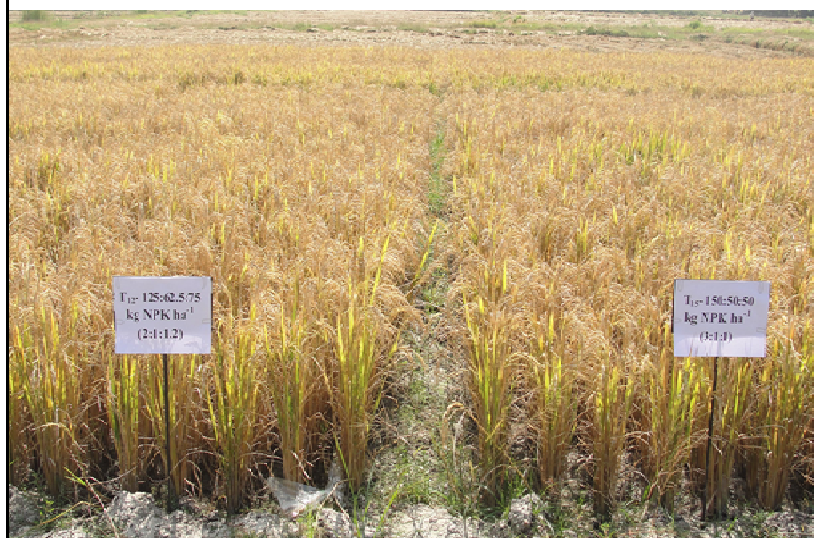


Plate 3: General view of the experimental plot at B block, V.C. Farm, Mandya.

3.6.3 Treatments

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K ratio
	kg ha ⁻¹			
T ₁	100	37.5	50	2.7:1:1.3
T ₂	100	37.5	75	2.7:1:2.0
T ₃	100	50	50	2.0:1:1.0
T ₄	100	50	75	2.0:1:1.5
T ₅	100	62.5	50	1.6:1:0.8
T ₆	100	62.5	75	1.6:1:1.2
T ₇	125	37.5	50	3.3:1:1.3
T ₈	125	37.5	75	3.3:1:2.0
T ₉	125	50	50	2.5:1:1.0
T ₁₀	125	50	75	2.5:1:1.5
T ₁₁	125	62.5	50	2.0:1:0.8
T ₁₂	125	62.5	75	2.0:1:1.2
T ₁₃	150	37.5	50	4.0:1:1.3
T ₁₄	150	37.5	75	4.0:1:2.0
T ₁₅	150	50	50	3.0:1:1.0
T ₁₆	150	50	75	3.0:1:1.5
T ₁₇	150	62.5	50	2.4:1:0.8
T ₁₈	150	62.5	75	2.4:1:1.2
T ₁₉	0	0	0	0:0:0

Note: FYM @ 10 t ha⁻¹ and ZnSO₄ @ 20 kg ha⁻¹ were applied for all the treatments

3.7 Crop husbandry

3.7.1 Preparation of nursery and rising of seedlings

Raised dry nursery beds were prepared and pre-germinated rice seeds were broadcasted on the beds and covered with thin film of soil + FYM mixture (2:1). Water was sprinkled with the help of rose-can. After 10 days of sowing, 150 g of urea, 50 g single super phosphate and 50 g muriate of potash were applied by broadcasting and 30 days old seedlings were transplanted in the experimental plots.

3.7.2 Imposition of treatments

On the day of planting, the soil was once again puddled and leveled using spade. Calculated quantities of fertilizers were applied to the plots where 50 per cent of the recommended dose of nitrogen and potassium and 100 per cent recommended dose of phosphorus was applied before transplanting and the rest was applied at 30 days after transplanting of rice. FYM @ 10 t ha⁻¹ and ZnSO₄ @ 20 kg ha⁻¹ were applied in common for all the treatments.

Thirty days old seedlings raised in a dry nursery were transplanted in the plots maintaining 20 cm between rows and 10 cm between hills. Immediately after transplanting, butachlor 50 EC @ 1 kg a.i. ha⁻¹ was applied and later hand weeding at 30 and 55 days after transplanting was done. Plant protection measures were undertaken as and when pests and diseases were noticed.

3.7.3 Irrigation schedule

After transplanting, 1 cm of standing water was maintained during first ten days and then gradually it was increased to 5 cm and maintained throughout crop growth period. Irrigation was stopped 10 days before harvesting of crop to facilitate easy harvesting.

3.7.4 Collection of data and plant sampling procedures

3.7.4.1 Growth and yield parameters

For the purpose of recording the growth and yield parameters, five hills from net plot of each treatment in each replication were selected at random and tagged for the purpose of recording various growth parameters. The following growth and yield parameters were recorded.

- (i) Plant height at harvest was recorded by selecting the tallest tiller in each identified hill from the base of the plant till the top most panicle in the plant.
- (ii) Number of tillers per hill was recorded in the tagged hills at harvest stage of the crop and the average value was computed.
- (iii) Number of productive tillers per hill was also recorded in the same five hills tagged for the purpose and the average value was calculated.
- (iv) Test weight: One thousand grains were counted from grains obtained from randomly selected panicles and their weight was recorded and expressed in grams
- (iv) Grain and straw yield of the crop was recorded after drying the produce under sun.

3.7.4.2 Harvesting and threshing

The crop was harvested after attaining the physiological maturity. Two rows on all the sides of each plot were harvested as border rows and the remaining area was treated as net plot. The crop in each net plot was harvested and threshed separately. The grains were cleaned and weight was recorded at 14 per cent moisture content. The straw from the individual plot was sun dried and weighed. The grain and straw yield were recorded and expressed in quintals per hectare.

3.8 Soil sampling

Representative soil samples were collected at 0-15 cm and 15-30 cm depth from each plot after harvest of the crop. Soil samples were shade dried, powdered and analyzed for different parameters like pH, EC_e, OC, available nutrients status (N, P, K, S, Ca, Mg,

Fe, Mn, Cu, Zn), and hot water soluble boron and Na content following standard procedures as described earlier in section 3.4.

3.9 Plant sampling

Grain and straw samples were collected separately from each plot soon after the harvest of the crop. The samples were initially air-dried cut to pieces and then oven dried at 70⁰ C overnight, later ground in willey mill and stored in glass bottles. The powdered grain and straw samples drawn at harvest from each treatment in each replication were analysed for total N, P, K, Ca, Mg, S, Na, Fe, Zn, Mn, Cu and B content following standard procedures and then the uptake of nutrients was calculated.

3.9.1 Total nitrogen

Total nitrogen content of plant samples was determined by Kjeldahl's digestion-distillation method. Powdered sample of 0.3 g was digested using concentrated H₂SO₄ in presence of digestion mixture (containing K₂SO₄ and CuSO₄ 5H₂O and selenium in the ratio 100:20:1) and distilled in alkaline medium. The liberated NH₃⁺ was trapped in boric acid containing mixed indicator and titrated against standard H₂SO₄ as described by Piper (1966).

3.9.2 Digestion of plant samples with Di-acid mixture

Powdered plant sample of 1.0 g was pre digested with conc. HNO₃ overnight and then digested with di-acid mixture containing HNO₃ and HClO₄ in the proportion of 9:4 till a snow white residue was obtained (Piper, 1966). The volume of the digest was made to 100 ml with distilled water and used it for total elemental analysis as detailed below.

3.9.3 Total phosphorus

A known volume of the di-acid digest (5 ml) was taken for total phosphorus determination by vandomolybdophosphoric yellow colour method in nitric acid system as described by Piper (1966).

3.9.4 Total potassium

Two ml of the di-acid digest was diluted to 25 ml with distilled water and fed to a calibrated flame photometer. By comparing the flame photometer readings of the sample with the calibration curve of potassium, the per cent potassium in the plant sample was calculated (Piper, 1966).

3.9.5 Calcium and magnesium

Five ml of the di-acid digest was titrated against standard EDTA after adding necessary reagents required for calcium and calcium plus magnesium as described by Piper (1966).

3.9.6 Total sulphur

Sulphur present in di-acid digest of the plant materials was determined by precipitating the sulphate with barium chloride and turbidity was measured at 420 nm using spectrophotometer as described by Page *et al.* (1982).

3.9.7 Total sodium

Two ml of the di-acid digest was diluted to 25 ml with distilled water and fed to a calibrated flame photometer. By comparing the flame photometer readings of the sample with the calibration curve of sodium, per cent sodium in the plant sample was calculated (Piper, 1966).

3.9.8 Micronutrients (Cu, Fe, Zn and Mn)

Micronutrients (Cu, Fe, Zn and Mn) concentration in the di-acid extract were determined by feeding in to atomic absorption spectrophotometer (AAS) under suitable measuring conditions (Page *et al.*, 1982).

3.9.9 Boron

Boron concentration in di-acid digested plant sample was estimated using Azomethine-H reagent method by using continuous flow analyzer (Page *et al.*, 1982).

3.10 Nutrient uptake by crop

After estimating the nutrient content of grains and straw by adopting standard chemical analytical methods, nutrient uptake (kg ha^{-1}) by crop was calculated for each treatment separately using the following formula,

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (\%)}}{100} \times \text{Biomass yield (kg ha}^{-1}\text{)}$$

3.11 Nutrient use efficiency

The nitrogen, phosphorus and potassium use efficiency were calculated using the following formula

1	$\text{NUE (kg N/ kg applied N)} = \frac{\text{Nitrogen uptake in fertilizer treatment plot} - \text{Nitrogen uptake in control plot}}{\text{Nitrogen applied}}$
2	$\text{PUE (kg P}_2\text{O}_5/\text{ kg applied P)} = \frac{\text{Phosphorus uptake in fertilizer treatment plot} - \text{Phosphorus uptake in control plot}}{\text{Phosphorus applied}}$
3	$\text{KUE (kg K}_2\text{O/ kg applied K)} = \frac{\text{Potassium uptake in fertilizer treatment plot} - \text{Potassium uptake in control plot}}{\text{Potassium applied}}$

3.12 Economics

Economics of rice cultivation was calculated in terms of rupees per hectare. The price in rupees of the inputs that were prevailing at the time of their use was considered for working out the economics of various treatment combinations. The net return per hectare was calculated by deducting the cost of cultivation per hectare from gross income per hectare. Benefit cost ratio was worked out as under

$$\text{Benefit: Cost ratio} = \frac{\text{Net income (Rs ha}^{-1}\text{)}}{\text{Cost of cultivation (Rs ha}^{-1}\text{)}}$$

3.13 Statistical analysis and interpretation of data

The relationship between different soil properties was worked out using simple correlation. The analysis and interpretation of the field experiment data was done using the Fisher's method of analysis of variance technique as given by Panse and Sukhatme (1978). The level of significance used in 'F' and 't' test was P=0.05 probability level and wherever 'F' test was found significant, the 't' test was performed to estimate critical differences among various treatments.

3.14 Spatial analysis of soil variables

The interpolation by ordinary kriging method was done on the soil variables. Different krig maps were prepared displaying the fuzzy distribution pattern using Arc Map 10.2.2 GIS software.

IV. EXPERIMENTAL RESULTS

The results of the investigation undertaken to characterize salt affected soils in Cauvery Command Area (CCA) of Karnataka by collecting surface (0-15 cm) and subsurface (15-30 cm) soil samples as well as profile samples, and field experiments conducted at ZARS, V.C. Farm, Mandya for two seasons (*Kharif* 2013 and summer 2014) to study the effect of nutrients levels and ratios on growth and yield of rice in gypsum amended sodic soils are presented in this chapter under the following headings:

4.1 Characteristics of salt affected soils

A. Physico-chemical and chemical properties of surface and subsurface soil samples of Cauvery command area.

The analytical results (ranges and mean values) of soil samples collected from two depths i.e. surface (0 - 15 cm) and subsurface (15-30 cm) from four salt affected sites are given in Tables 4.1 to 4.5.

4.1.1 Soil pH

The pH of surface soils ranged from 7.0 to 9.8 in site one (B Block), 6.2 to 10.6 in site two (D Block), 7.0 to 10.4 in site three (Ulalla) and 8.5 to 10.0 in site four (Upennole) with mean values of 8.5, 8.8, 8.8 and 9.4, respectively (Table 4.1).

In subsurface soil, the pH varied from 7.1 to 9.9, 6.2 to 10.7, 7.6 to 10.1 and 8.8 to 10.3 in site one, site two, site three and site four, respectively. The mean pH values for the four sites were 8.8, 9.0, 8.7 and 9.7, respectively.

4.1.2 Electrical conductivity

Electrical conductivity of saturation extract (EC_e) gives an indication about salt concentration of soil. EC_e of surface soils ranged from 0.9 to 6.3 dS m⁻¹ in site one, 1.1 to 11.7 dS m⁻¹ in site two, 0.4 to 10.4 dS m⁻¹ in site three and 1.1 to 9.7 dS m⁻¹ in site four. The mean values were 2.3, 4.5, 2.8 and 4.3 dS m⁻¹, respectively (Table 4.1).

Table 4.1: Physico-chemical characteristics of the surface and subsurface samples of salt affected soils in Cauvery command area.

Sites	pH	ECe (dS m ⁻¹)	Exchangeable Ca [cmol(p ⁺) kg ⁻¹]	Exchangeable Mg [cmol (p ⁺)kg ⁻¹]	Exchangeable Na [cmol(p ⁺)kg ⁻¹]	Exchangeable K [cmol (p ⁺)kg ⁻¹]	CEC [cmol(p ⁺)kg ⁻¹]
Surface layer (0-15cm)							
Site 1 (B block)	8.5 (7.0-9.8)	2.3 (0.9-6.3)	10.1 (4.6-19.0)	5.0 (1.4-8.8)	2.8 (0.3-10.5)	0.31 (0.10-0.51)	19.3 (11.0-29.6)
Site 2 (D block)	8.8 (6.2-10.6)	4.5 (1.1-11.7)	11.7 (5.2-20.0)	4.8 (1.0-12.2)	3.8 (0.3-10.3)	0.19 (0.07-0.38)	21.7 (13.2-33.0)
Site 3 (Ulalla)	8.8 (7.0-10.4)	2.8 (0.4-10.4)	8.5 (3.4-13.8)	8.8 (3.2-16.4)	1.8 (0.4-4.4)	0.26 (0.17-0.66)	20.6 (9.8-30.8)
Site 4 (Upenmole)	9.4 (8.5-10.0)	4.3 (1.1-9.7)	11.1 (5.0-16.8)	4.7 (2.0-7.8)	5.1 (0.5-9.2)	0.21 (0.09-0.43)	22.2 (16.0-30.8)
Subsurface layer (15-30cm)							
Site 1 (B block)	8.8 (7.1-9.9)	2.5 (1.0-5.4)	10.8 (5.2-21.8)	4.0 (1.4-7.0)	3.5 (0.3-9.4)	0.26 (0.14-0.40)	19.7 (11.0-30.1)
Site 2 (D block)	9.0 (6.2-10.7)	4.0 (0.7-12.3)	10.2 (4.4-22.0)	4.0 (0.4-9.6)	3.7 (0.3-9.7)	0.18 (0.09-0.51)	19.3 (7.9-34.7)
Site 3 (Ulalla)	8.7 (7.6-10.1)	2.6 (0.7-8.8)	7.7 (2.4-12.4)	8.8 (3.4-15.4)	1.9 (0.5-6.6)	0.23 (0.13-0.48)	19.8 (12.7-28.3)
Site 4 (Upenmole)	9.7 (8.8-10.3)	4.8 (0.8-12.6)	10.1 (5.6-15.8)	5.1 (0.6-10.4)	6.1 (0.3-12.4)	0.17 (0.08-0.30)	22.7 (13.6-32.4)

The values within the parentheses indicate the range.

In subsurface soils, it ranged from 1.0 to 5.4, 0.7 to 12.3, 0.7 to 8.8 and 0.8 to 12.6 dS m⁻¹ in site one, site two, site three and site four, respectively. The mean ECe values for the four sites were 2.5, 4.0, 2.6 and 4.8 dS m⁻¹, respectively.

4.1.3 Exchangeable calcium

Calcium dominated the exchange complex in both surface and subsurface soils followed by magnesium and/or sodium and potassium (Table 4.1). The exchangeable calcium content (exch. Ca) in surface soils ranged from 4.6 to 19.0 cmol (p⁺) kg⁻¹ in site one, 5.2 to 20.0 cmol (p⁺) kg⁻¹ in site two, 3.4 to 13.8 cmol (p⁺) kg⁻¹ in site three, 5.0 to 16.8 cmol (p⁺) kg⁻¹ in site four with mean value of 10.1, 11.7, 8.5 and 11.1 cmol (p⁺) kg⁻¹, respectively.

In subsurface soils, the exch. Ca content ranged from 5.2 to 21.8 cmol (p⁺) kg⁻¹ (site 1), 4.4 to 22.0 cmol (p⁺) kg⁻¹ (site 2), 2.4 to 12.4 cmol (p⁺) kg⁻¹ (site 3) and 5.6 to 15.8 cmol (p⁺) kg⁻¹ (site 4). The mean exch.Ca values for the four sites were 10.8, 10.2, 7.7 and 10.1 cmol (p⁺) kg⁻¹, respectively.

4.1.4 Exchangeable magnesium

The exchangeable magnesium (exch. Mg) content of the surface soils ranged from 1.4 to 8.8, 1.0 to 12.2, 3.2 to 16.4 and 2.0 to 7.8 cmol (p⁺) kg⁻¹ in site one, site two, site three and site four, respectively (Table 4.1). The mean exch. Mg values for the four sites were 5.0, 4.8, 8.8 and 4.7 cmol (p⁺) kg⁻¹, respectively.

In subsurface soils, the exch. Mg. content ranged from 1.4 to 7.0 cmol (p⁺) kg⁻¹ in site one, 0.4 to 9.6 cmol (p⁺) kg⁻¹ in site two, 3.4 to 15.4 cmol (p⁺) kg⁻¹ in site three and 0.6 to 10.4 cmol (p⁺) kg⁻¹ in site four with mean value of 4.0, 4.0, 8.8 and 5.1 cmol (p⁺) kg⁻¹, respectively.

4.1.5 Exchangeable sodium

In surface soils, the exchangeable sodium content (exch. Na) ranged from 0.3 to 10.5 in site one, 0.3 to 10.3 in site two, 0.4 to 4.4 in site three, 0.5 to 9.2 in site four with mean value of 2.8, 3.8, 1.8 and 5.1 cmol (p⁺) kg⁻¹, respectively (Table 4.1).

In subsurface soils, the exch. Na content ranged from 0.3 to 9.4, 0.3 to 9.7, 0.5 to 6.6 and 0.3 to 12.4 cmol (p⁺) kg⁻¹ in site 1, site 2, site 3 and site 4, respectively. The mean exch. Na values for the four sites were 3.5, 3.7, 1.9 and 6.1 cmol (p⁺) kg⁻¹, respectively.

4.1.6 Exchangeable potassium

The exchangeable potassium (exch. K) content of the surface soils ranged from 0.10 to 0.51, 0.07 to 0.38, 0.17 to 0.66 and 0.09 to 0.43 cmol (p⁺) kg⁻¹ in site 1, 2, 3 and site 4, respectively (Table 4.1). The mean exch. K values for the four sites were 0.31, 0.19, 0.26 and 0.21 cmol (p⁺) kg⁻¹, respectively.

In subsurface soils, the exch. K content in site 1, site 2, site 3 and site 4 ranged from 0.14 to 0.40 cmol(p⁺)kg⁻¹, 0.09 to 0.51 cmol (p⁺) kg⁻¹, 0.13 to 0.48 cmol (p⁺) kg⁻¹ and 0.08 to 0.30 cmol (p⁺) kg⁻¹ with mean value of 0.26, 0.18, 0.23 and 0.17 cmol (p⁺) kg⁻¹, respectively .

4.1.7 Cation exchange capacity

The cation exchange capacity (CEC) in first depth ranged from 11.0 to 29.6 cmol (p⁺) kg⁻¹ in site one, 13.2 to 33.0 cmol (p⁺) kg⁻¹ in site two, 9.8 to 30.8 in site three, 16.0 to 30.8 cmol (p⁺) kg⁻¹ in site four with mean values of 19.3, 21.7, 20.6 and 22.2 cmol (p⁺) kg⁻¹, respectively (Table 4.1).

In subsurface, the CEC of soils ranged from 11.0 to 30.1, 7.9 to 34.7, 12.7 to 28.3 and 13.6 to 32.4 cmol (p⁺) kg⁻¹ in site 1, 2, 3 and site 4, respectively. The mean CEC values for the four study sites were 19.7, 19.3, 19.8 and 22.7 cmol (p⁺) kg⁻¹, respectively.

4.1.8 Exchangeable Sodium Percentage (ESP)

In surface soils, the exchangeable sodium percentage (ESP) of site 1, 2, 3 and 4 varied from 1.8 to 58.6, 1.1 to 44.7, 3.5 to 28.3 and 3.1 to 42.5 with a mean value of 14.1, 17.8, 9.1 and 22.7, respectively (Table 4.2). Whereas in subsurface soil, the ESP varied from 1.6 to 48.9, 2.5 to 45.8, 3.6 to 30.7 and 1.8 to 51.3 with mean values of 17.5, 18.3, 9.6 and 26.4 in site 1, 2, 3 and site 4, respectively.

Table 4.2: Exchangeable sodium percentage (ESP), Ca:Mg, Ca:Na ratio and ESI of the surface and subsurface samples of salt affected soils in Cauvery command area.

Sites	ESP	Ca:Mg	Ca:Na	ESI
Surface layer (0-15cm)				
Site 1 (B block)	14.1 (1.8-58.6)	2.3 (1.1-5.7)	8.1 (0.4-35.2)	0.05 (0.01-0.20)
Site 2 (D block)	17.8 (1.1-44.7)	3.8 (1.0-20.0)	7.1 (0.7-54.4)	0.06 (0.01-0.17)
Site 3 (Ulalla)	9.1 (3.5-28.3)	1.1 (0.4-2.6)	5.9 (0.9-16.4)	0.05 (0.01-0.26)
Site 4 (Upenmole)	22.7 (3.1-42.5)	2.6 (0.7-4.1)	4.5 (0.7-23.1)	0.04 (0.02-0.06)
Subsurface layer (15-30cm)				
Site 1 (B block)	17.5 (1.6-48.9)	3.1 (1.1-7.8)	8.1 (0.7-48.7)	0.04 (0.01-0.17)
Site 2 (D block)	18.3 (2.5-45.8)	5.1 (0.7-38.5)	6.6 (0.6-28.2)	0.05 (0.01-0.14)
Site 3 (Ulalla)	9.6 (3.6-30.7)	0.9 (0.3-2.1)	5.5 (0.7-14.0)	0.04 (0.01-0.24)
Site 4 (Upenmole)	26.4 (1.8-51.3)	3.6 (1.1-22.3)	6.3 (0.5-34.6)	0.04 (0.01-0.08)

The values within the parentheses indicate the range

4.1.9 Calcium: Magnesium ratio

Calcium to magnesium (Ca: Mg) ratio of surface soil ranged from 1.1 to 5.7 in site one, 1.0 to 20.0 in site two, 0.4 to 2.6 in site three and 0.7 to 4.1 in site four with mean values of 2.3, 3.8, 1.1 and 2.6, respectively (Table 4.2).

In subsurface soil, the Ca:Mg ratio ranged from 1.1 to 7.8, 0.7 to 38.5, 0.3 to 2.1 and 1.1 to 22.3 in site 1, 2, 3 and site 4, respectively. The mean Ca: Mg ratio values for the four sites were 3.1, 5.1, 0.9 and 3.6, respectively.

4.1.10 Calcium: Sodium ratio

Calcium: Sodium (Ca: Na) ratio in surface soil ranged from 0.4 to 35.2 in site one, 0.7 to 54.4 in site two, 0.9 to 16.4 in site three and 0.7 to 23.1 in site four (Table 4.2). The mean values for the four selected sites were 8.1, 7.1, 5.9 and 4.5.

In subsurface, it varied from 0.7 to 48.7, 0.6 to 28.2, 0.7 to 14.0 and 0.5 to 34.6 in soils of site 1, 2, 3 and site 4, respectively. The mean Ca: Na values for the four sites were 8.1, 6.6, 5.5 and 6.3, respectively.

4.1.11 Electrochemical Stability Index (ESI)

The ESI of surface soils varied from 0.01 to 0.20 in site one, 0.01 to 0.17 in site two, 0.01 to 0.26 in site three and 0.02 to 0.06 in site four with mean values of 0.05, 0.06, 0.05 and 0.04, respectively (Table 4.2).

In subsurface soils, the ESI value ranges from 0.01 to 0.17, 0.01 to 0.14, 0.01 to 0.24 and 0.01 to 0.08 in site 1, site 2 site 3 and site 4, respectively. The mean ESI values for the four sites were 0.04, 0.05, 0.04 and 0.04, respectively.

4.2 Water soluble ions content of salt affected soils of Cauvery command area

4.2.1 Soluble cations

4.2.1.1 Calcium

The calcium content of surface soils ranged from 0.48 to 2.38 me L⁻¹ in site one, 0.71 to 3.80 me L⁻¹ in site two, 0.71 to 1.66 me L⁻¹ in site three, 0.95 to 3.33 me L⁻¹ in site four with mean values of 1.30, 1.22, 1.07 and 1.64 me L⁻¹, respectively (Table 4.3).

Table 4.3: Water soluble ions content of the surface and subsurface samples of salt affected soils in Cauvery command area.

Sites	Calcium	Magnesium	Sodium	Potassium	Carbonates	Bicarbonates	Chlorides	Sulphates
	-----me L ⁻¹ -----							
Surface layer (0-15cm)								
Site 1 (B block)	1.30 (0.48-2.38)	0.66 (0.24-1.90)	3.19 (0.57-8.82)	0.27 (0.14-1.08)	1.02 (0.24-5.23)	1.49 (0.60-2.95)	2.47 (1.04-5.13)	1.08 (0.06-3.03)
Site 2 (D block)	1.22 (0.71-3.80)	0.51 (0.24-1.43)	3.57 (0.52-9.91)	0.24 (0.09-0.56)	0.64 (Tr-1.14)	1.56 (0.13-4.41)	2.83 (1.04-8.17)	1.10 (0.13-2.28)
Site 3 (Ulalla)	1.07 (0.71-1.66)	0.41 (0.24-1.66)	2.03 (0.18-8.57)	0.32 (0.14-1.27)	0.99 (tr-3.95)	1.02 (0.08-2.62)	2.36 (0.53-3.99)	0.69 (0.02-3.02)
Site 4 (Upenmole)	1.64 (0.95-3.33)	0.57 (0.24-1.90)	5.26 (0.86-9.66)	0.23 (0.10-0.51)	1.93 (tr-4.56)	1.17 (0.49-1.81)	3.97 (1.04-7.22)	0.69 (0.11-2.08)
Subsurface layer (15-30cm)								
Site 1 (B block)	1.31 (0.48-3.70)	0.82 (0.24-2.85)	3.07 (0.46-8.57)	0.28 (0.12-2.50)	1.08 (0.33-4.79)	1.66 (0.62-3.61)	2.45 (0.99-4.37)	0.92 (0.12-2.98)
Site 2 (D block)	0.91 (0.48-1.90)	0.43 (0.24-1.90)	3.30 (0.30-9.90)	0.26 (0.10-0.68)	0.31 (0.22-2.51)	1.54 (0.08-4.10)	2.24 (0.85-5.51)	0.85 (0.05-1.88)
Site 3 (Ulalla)	0.74 (0.24-1.66)	0.43 (0.19-1.43)	1.81 (0.38-4.94)	0.30 (0.13-0.74)	0.52 (tr-0.52)	1.29 (0.25-3.50)	1.85 (0.82-3.99)	0.60 (0.03-1.45)
Site 4 (Upenmole)	1.40 (0.71-2.85)	0.58 (0.24-1.66)	4.84 (0.54-10.30)	0.17 (0.10-0.27)	2.21 (tr-3.80)	1.56 (0.63-3.86)	3.25 (1.23-5.51)	0.59 (0.08-2.42)

The values within the parentheses indicate the range; tr- traces

In subsurface soils the calcium content ranged from 0.48 to 3.70, 0.48 to 1.90, 0.24 to 1.66 and 0.71 to 2.85 me L⁻¹ in site 1, site 2, site 3 and site 4, respectively. The mean calcium values for the four sites were 1.31, 0.91, 0.74 and 1.40 me L⁻¹, respectively.

4.2.1.2 Magnesium

In surface soils, the magnesium content ranged from 0.24 to 1.90 me L⁻¹ in site 1, 0.24 to 1.43 me L⁻¹ in site 2, 0.24 to 1.66 me L⁻¹ in site 3 and 0.24 to 1.90 me L⁻¹ in site 4 with mean value of 0.66, 0.51, 0.41 and 0.57 me L⁻¹, respectively (Table 4.3).

In subsurface, the Mg content of the soils ranged from 0.24 to 2.85, 0.24 to 1.90, 0.19 to 1.43 and 0.24 to 1.66 me L⁻¹ in site 1, site 2, site 3 and site 4, respectively. The mean Mg values for the four sites were 0.82, 0.43, 0.43 and 0.58 me L⁻¹, respectively.

4.2.1.3 Sodium

In surface soils, the sodium content ranged from 0.57 to 8.82 me L⁻¹ in site one, 0.52 to 9.91 me L⁻¹ in site two, 0.18 to 8.57 me L⁻¹ in site three, 0.86 to 9.66 me L⁻¹ in site four with mean value of 3.19, 3.57, 2.03 and 5.26 me L⁻¹, respectively (Table 4.3).

In subsurface, the Na content of soils ranged from 0.46 to 8.57, 0.30 to 9.90, 0.38 to 4.94 and 0.54 to 10.30 me L⁻¹ in site 1, site 2, site 3 and site 4, respectively. The mean Na values for the four sites were 3.07, 3.30, 1.81 and 4.84 me L⁻¹, respectively.

4.2.1.4 Potassium

The potassium content of the surface soils ranged from 0.14 to 1.08, 0.09 to 0.56, 0.14 to 1.27 and 0.10 to 0.51 me L⁻¹ in site 1, 2, 3 and site 4, respectively. The mean K values for the four sites were 0.27, 0.24, 0.32 and 0.23 me L⁻¹, respectively (Table 4.3).

In subsurface soils, the K content in site 1, site 2, site 3 and site 4 ranged from 0.12 to 2.50 me L⁻¹, 0.10 to 0.68 me L⁻¹, 0.13 to 0.74 me L⁻¹ and 0.10 to 0.27 me L⁻¹ with mean value of 0.28, 0.26, 0.30 and 0.17 me L⁻¹, respectively.

4.2.2 Soluble anions

4.2.2.1 Carbonates

The carbonates content of soil in surface layer ranged from 0.24 to 5.23 me L⁻¹ in site one, traces to 1.14 me L⁻¹ in site two, traces to 3.95 me L⁻¹ in site three, traces to 4.56 me L⁻¹ in site four with mean values of 1.02, 0.64, 0.99 and 1.93 me L⁻¹, respectively (Table 4.3).

In subsurface layer, the carbonate content of soils ranged from 0.33 to 4.79, 0.22 to 2.51, traces to 0.52 and traces to 3.80 me L⁻¹ in site 1, 2, 3 and site 4, respectively. The mean carbonate values for the four study sites were 1.08, 0.31, 0.52 and 2.21 me L⁻¹, respectively.

4.2.2.2 Bicarbonates

The bicarbonate content of surface soils ranged from 0.60 to 2.95 me L⁻¹ in site one, 0.13 to 4.41 me L⁻¹ in site two, 0.08 to 2.62 me L⁻¹ in site three and 0.49 to 1.81 me L⁻¹ in site four with mean values of 1.49, 1.56, 1.02 and 1.17 me L⁻¹, respectively (Table 4.3).

In subsurface soils, the bicarbonate content varied from 0.62 to 3.61 me L⁻¹, 0.08 to 4.10 me L⁻¹, 0.25 to 3.50 me L⁻¹ and 0.63 to 3.86 me L⁻¹ in site 1, site 2, site 3 and site 4, respectively. The mean value for the four sites was 1.66, 1.54, 1.29 and 1.56 me L⁻¹, respectively.

4.2.2.3 Chlorides

The chloride content in surface soils ranged from 1.04 to 5.13 me L⁻¹ in site one, 1.04 to 8.17 me L⁻¹ in site two, 0.53 to 3.99 me L⁻¹ in site three and 1.04 to 7.22 me L⁻¹ in site four with mean value of 2.47, 2.83, 2.36 and 3.97 me L⁻¹, respectively (Table 4.3).

In subsurface soils, the chloride content ranged from 0.99 to 4.37 me L⁻¹, 0.85 to 5.51 me L⁻¹, 0.82 to 3.99 me L⁻¹ and 1.23 to 5.51 me L⁻¹ in site 1, 2, 3 and site 4, respectively. The mean chloride values for the four sites were 2.45, 2.24, 1.85 and 3.25 me L⁻¹, respectively.

4.2.2.4 Sulphates

The sulphate content of the surface samples of site 1, site 2, site 3 and site 4 ranged from 0.06 to 3.03 me L⁻¹, 0.13 to 2.28 me L⁻¹, 0.02 to 3.02 me L⁻¹ and 0.11 to 2.08 me L⁻¹ with mean value of 1.08, 1.10, 0.69 and 0.69 me L⁻¹, respectively (Table 4.3).

In subsurface soil, the sulphate content ranged from 0.12 to 2.98 me L⁻¹, 0.05 to 1.88 me L⁻¹, 0.03 to 1.45 me L⁻¹ and 0.08 to 2.42 me L⁻¹ in site 1, site 2, site 3 and site 4 with mean value being 0.92, 0.85, 0.60 and 0.59 me L⁻¹, respectively.

4.3 Chemical properties of salt affected soils of Cauvery command area

4.3.1 Organic carbon

The organic carbon (OC) content of soils ranged from 2.2 to 9.2, 0.9 to 28.2, 1.9 to 15.9 and 0.4 to 5.3 g kg⁻¹ in site 1, site 2, site 3 and site 4 in surface soils with mean values of 5.4, 8.1, 6.9 and 3.2 g kg⁻¹, respectively (Table 4.4).

The organic carbon content in subsurface soils ranged from 1.5 to 7.5 g kg⁻¹ in site one, 0.3 to 29.1 g kg⁻¹ in site two, 1.7 to 8.6 g kg⁻¹ in site three and 0.3 to 2.9 g kg⁻¹ in site four, respectively. The mean value of the four sites was 3.8, 6.3, 4.4 and 1.6 g kg⁻¹, respectively.

4.3.2 Available nitrogen

The available nitrogen (Av. N) content of soils ranged from 112.9 to 474.2, 80.3 to 723.8, 170.6 to 513.0 and 62.7 to 217.0 kg ha⁻¹ in site 1, site 2, site 3 and site 4 in surface soils with mean values of 287.5, 295.5, 292.1 and 141.4 kg ha⁻¹, respectively (Table 4.4).

In subsurface soils, the available N content ranged from 84.0 to 307.3, 75.3 to 442.3, 107.9 to 313.6 and 43.9 to 145.5 kg ha⁻¹ in site 1, 2, 3 and site 4, respectively with mean value being 204.5, 211.4, 232.5 and 82.5 kg ha⁻¹, respectively.

Table 4.4: Organic carbon and nutrient status of the surface and subsurface samples of salt affected soils in Cauvery command area.

Sites	OC (g kg⁻¹)	Available nitrogen (kg ha⁻¹)	Available phosphorus (P₂O₅) (kg ha⁻¹)	Available potassium (K₂O) (kg ha⁻¹)	Available sulphur (mg kg⁻¹)
Surface layer (0-15cm)					
Site 1 (B block)	5.4 (2.2-9.2)	287.5 (112.9-474.2)	30.9 (12.1-50.6)	283.4 (94.8-435.6)	38.7 (11.7-82.6)
Site 2 (D block)	8.1 (0.9-28.2)	295.5 (80.3-723.8)	29.8 (11.0-47.5)	179.1 (66.0-308.8)	24.1 (6.0-48.5)
Site 3 (Ulalla)	6.9 (1.9-15.9)	292.1 (170.6-513.0)	16.8 (2.6-52.4)	267.0 (178.8-471.7)	20.7 (3.0-98.3)
Site 4 (Upenmole)	3.2 (0.4-5.3)	141.4 (62.7-217.0)	19.6 (6.3-34.4)	190.5 (81.6-339.6)	10.9 (1.5-27.8)
Subsurface layer (15-30cm)					
Site 1 (B block)	3.8 (1.5-7.5)	204.5 (84.0-307.3)	18.5 (4.8-35.9)	242.9 (129.6-374.4)	30.0 (5.7-83.5)
Site 2 (D block)	6.3 (0.3-29.1)	211.4 (75.3-442.3)	12.5 (1.8-25.6)	166.6 (80.4-328.8)	19.3 (2.3-48.1)
Site 3 (Ulalla)	4.4 (1.7-8.6)	232.5 (107.9-313.6)	10.3 (1.0-51.7)	241.9 (131.7-423.4)	18.0 (0.8-96.4)
Site 4 (Upenmole)	1.6 (0.3-2.9)	82.5 (43.9-145.5)	13.2 (6.3-28.9)	160.9 (79.2-277.2)	13.7 (0.4-32.9)

The values within the parentheses indicate the range.

4.3.3 Available phosphorus

The available phosphorus content (Av. P_2O_5) in the surface samples of site 1, site 2, site 3 and site 4 ranged from 12.1 to 50.6, 11.0 to 47.5, 2.6 to 52.4 and 6.3 to 34.4 $kg\ ha^{-1}$ with mean value of 30.9, 29.8, 16.8 and 19.6 $kg\ ha^{-1}$, respectively (Table 4.4).

In subsurface soil, the available P_2O_5 content ranged from 4.8 to 35.9, 1.8 to 25.6, 1.0 to 51.7 and 6.3 to 28.9 $kg\ ha^{-1}$ in site 1, site 2, site 3 and site 4, respectively with mean value being 18.5, 12.5, 10.3 and 13.2 $kg\ ha^{-1}$, respectively.

4.3.4 Available potassium

In the surface soil samples of sites 1, 2, 3 and 4 the available potassium content ranged from 94.8 to 435.6, 66.0 to 308.8, 178.8 to 471.7 and 81.6 to 339.6 $kg\ ha^{-1}$ with mean value of 283.4, 179.1, 267.0 and 190.5 $kg\ ha^{-1}$, respectively (Table 4.4).

In subsurface soils, the available K_2O content ranged from 129.6 to 374.4, 80.4 to 328.8, 131.7 to 423.4 and 79.2 to 277.2 $kg\ ha^{-1}$ in site 1, site 2, site 3 and site 4, respectively. The mean K_2O values for the four sites were 242.9, 166.6, 241.9 and 160.9 $kg\ ha^{-1}$, respectively.

4.3.5 Available sulphur (SO_4-S)

The available sulphur content (avail. S) in surface soils ranged from 11.7 to 82.6 $mg\ kg^{-1}$ in site one, 6.0 to 48.5 $mg\ kg^{-1}$ in site two, 3.0 to 98.3 $mg\ kg^{-1}$ in site three and 1.5 to 27.8 $mg\ kg^{-1}$ in site four with mean value of 38.7, 24.1, 20.7 and 10.9 $mg\ kg^{-1}$, respectively (Table 4.4).

In subsurface, the available S content of soils ranged from 5.7 to 83.5, 2.3 to 48.1, 0.8 to 96.4 and 0.4 to 32.9 $mg\ kg^{-1}$ in site 1, 2, 3 and 4, respectively. The mean avail. S values for the four sites were 30.0, 19.3, 18.0 and 13.7 $mg\ kg^{-1}$, respectively.

4.3.6 DTPA zinc

The DTPA-Zn content of surface soils ranged from 0.45 to 3.64 $mg\ kg^{-1}$, 0.16 to 1.52 $mg\ kg^{-1}$, 0.14 to 0.68 $mg\ kg^{-1}$ and 0.30 to 0.87 $mg\ kg^{-1}$ in site 1, 2, 3 and site 4 with mean values of 1.88, 0.49, 0.33 and 0.56 $mg\ kg^{-1}$, respectively (Table 4.5).

Table 4.5: Micronutrient status (mean and range) in surface and subsurface samples of salt affected soils in Cauvery command area.

Sites	DTPA- Zn (mg kg⁻¹)	DTPA-Cu (mg kg⁻¹)	DTPA- Fe (mg kg⁻¹)	DTPA- Mn (mg kg⁻¹)	Hot water soluble B (mg kg⁻¹)
Surface layer (0-15cm)					
Site 1 (B block)	1.88 (0.45-3.64)	1.84 (0.1-4.25)	22.85 (9.0-38.45)	8.88 (0.65-18.59)	0.77 (0.18-1.20)
Site 2 (D block)	0.49 (0.16-1.52)	1.96 (0.53-6.38)	16.81 (2.48-71.22)	13.94 (3.44-41.10)	0.76 (0.20-3.70)
Site 3 (Ulalla)	0.33 (0.14-0.68)	2.33 (1.09-4.21)	17.23 (7.73-27.86)	8.53 (3.48-18.46)	0.73 (0.20-4.14)
Site 4 (Upenmole)	0.56 (0.30-0.87)	1.65 (0.76-2.74)	11.48 (5.21-18.42)	16.58 (7.18-22.94)	0.19 (0.10-0.70)
Subsurface layer (15-30cm)					
Site 1 (B block)	1.26 (0.45-2.75)	1.80 (0.10-4.77)	18.87 (8.14-36.0)	9.28 (0.55-18.04)	0.89 (0.20-1.88)
Site 2 (D block)	0.38 (0.11-1.36)	1.72 (0.49-6.65)	15.87 (2.29-73.82)	11.77 (3.80-35.20)	0.71 (0.18-4.10)
Site 3 (Ulalla)	0.25 (0.10-0.91)	2.21 (1.20-3.56)	13.75 (6.23-27.56)	8.64 (4.24-17.61)	0.49 (0.11-2.72)
Site 4 (Upenmole)	0.54 (0.29-0.91)	1.47 (0.70-2.41)	9.05 (3.67-19.01)	13.42 (5.37-22.36)	0.19 (0.08-0.80)

The values within the parentheses indicate the range

In subsurface, the DTPA-Zn content of soils ranged from 0.45 to 2.75, 0.11 to 1.36, 0.10 to 0.91 and 0.29 to 0.91 mg kg⁻¹ in site 1, 2, 3 and 4, respectively. The mean DTPA-Zn values for the four sites were 1.26, 0.38, 0.25 and 0.54 mg kg⁻¹, respectively.

4.3.7 DTPA copper

The range of DTPA-Cu status in the surface soil samples of study sites 1, 2, 3 and 4 was 0.1 to 4.25, 0.53 to 6.38, 1.09 to 4.21 and 0.76 to 2.74 mg kg⁻¹ and the mean value for each of the site was 1.84, 1.96, 2.33 and 1.65 mg kg⁻¹, respectively (Table 4.5).

In subsurface soils, the DTPA-Cu content of soils ranged from 0.10 to 4.77, 0.49 to 6.65, 1.20 to 3.56 and 0.70 to 2.41 mg kg⁻¹ in site 1, site 2, site 3 and site 4, respectively. The mean DTPA-Cu values were 1.80, 1.72, 2.21 and 1.47 mg kg⁻¹, respectively.

4.3.8 DTPA iron

The surface soil samples of study site 1, 2, 3 and 4 had the DTPA-Fe content in the range of 9.0 to 38.45, 2.48 to 71.22, 7.73 to 27.86 and 5.21 to 18.42 mg kg⁻¹ with mean value of 22.85, 16.81, 17.23 and 11.48 mg kg⁻¹, respectively (Table 4.5). While in the subsurface soils it ranged from 8.14 to 36.0, 2.29 to 73.82, 6.23 to 27.56 and 3.67 to 19.01 mg kg⁻¹ with the mean DTPA-Fe values of 18.87, 15.87, 13.75 and 9.05 mg kg⁻¹, respectively.

4.3.9 DTPA manganese

The DTPA-Mn content in surface soils ranged from 0.65 to 18.59 mg kg⁻¹ in site one, 3.44 to 41.10 mg kg⁻¹ in site two, 3.48 to 18.46 mg kg⁻¹ in site three, 7.18 to 22.94 mg kg⁻¹ in site four with mean value of 8.88, 13.94, 8.53 and 16.58 mg kg⁻¹, respectively (Table 4.5).

The DTPA-Mn content of subsurface soils ranged from 0.55 to 18.04, 3.80 to 35.20, 4.24 to 17.61 and 5.37 to 22.36 mg kg⁻¹ in site 1, site 2, site 3 and site 4, respectively. The mean DTPA-Mn values for the four sites were 9.28, 11.77, 8.64 and 13.42 mg kg⁻¹, respectively.

4.3.10 Hot water soluble boron

The hot water soluble boron (available B) content in surface soils of sites 1, 2, 3 and 4 ranged from 0.18 to 1.20, 0.20 to 3.70, 0.20 to 4.14, 0.10 to 0.70 mg kg⁻¹ with mean value of 0.77, 0.76, 0.73 and 0.19 mg kg⁻¹, respectively (Table 4.5).

The avail. B content of subsurface soils ranged from 0.20 to 1.88, 0.18 to 4.10, 0.11 to 2.72 and 0.08 to 0.80 mg kg⁻¹ in site 1, site 2, site 3 and site 4, respectively. The mean avail. B content for the four sites was 0.89, 0.71, 0.49 and 0.19 mg kg⁻¹, respectively.

4.4 Correlation among selected soil parameters at 0-15 cm and 15-30 cm depth

Simple correlation between some of the characters of surface samples (Table 4.6) analysed indicate that the soil pH was significantly and positively correlated with ECe (0.492**), ESP (0.651**), exch. Na (0.603**), CO₃²⁻ (0.594**) and Cl⁻ (0.279**), whereas it was negatively and significantly with ESI (-0.234**), organic carbon (-0.618**), Ca²⁺ (-0.249**) and Mg²⁺ (-0.256**).

In subsurface samples, (Table 4.7) the pH was positively correlated with ECe (0.592**), ESP (0.758**), exch. Na (0.749**), CO₃²⁻ (0.626**), HCO₃⁻ (0.379**) and Cl⁻ (0.309**). However, it was negatively correlated with ESI (-0.372**), organic carbon (-0.578**) and Mg²⁺ (-0.227**).

4.5 Physico-chemical properties of salt affected soil profile samples

4.5.1 Physical properties

The physical properties of profile samples viz., particle size distribution, bulk density and water holding capacity are presented in Tables 4.8 to 4.11.

4.5.1.1 Site 1

The sand content in the surface horizon of profile 1 (P₁) was 64.3 per cent and in subsurface horizons it ranged from 41.3 to 67.9 per cent (Table 4.8). Maximum was observed in the last horizon (115-140 cm) and was lowest in second horizon (15-30 cm). The silt content was higher in the second horizon (20.8 per cent) and minimum was

Table 4.6: Correlation matrix for some selected soil characters at 0-15 cm depth.

	pH	ECe	CEC	ESP	Na⁺	ESI	OC	Ca²⁺	Mg²⁺	CO₃²⁻	HCO₃⁻	Cl⁻
ECe	0.492**											
CEC	-0.053	0.208*										
ESP	0.651**	0.659**	0.039									
Na⁺	0.603**	0.685**	0.293**	0.948**								
ESI	-0.234**	0.268**	0.155	-0.312**	-0.254**							
OC	-0.618**	-0.080	0.351**	-0.346**	-0.283**	0.242**						
Ca²⁺	-0.249**	-0.060	0.696**	-0.206*	-0.007	0.238**	0.401**					
Mg²⁺	-0.256**	-0.130	0.542**	-0.416**	-0.287**	0.161	0.308**	0.001				
CO₃⁻	0.594**	0.704**	0.096	0.745**	0.734**	0.014	-0.470**	-0.076	-0.326**			
HCO₃²⁻	0.158	0.244**	-0.107	0.282**	0.213**	0.086	-0.011	0.040	-0.349**	0.275**		
Cl⁻	0.279**	0.451**	0.196*	0.470**	0.549**	0.016	-0.289**	0.066	-0.177*	0.413**	0.142	
SO₄²⁻	0.105	0.650**	0.119	0.346**	0.361**	0.277**	0.171*	-0.045	-0.041	0.529**	0.215**	0.254**

• * Significant at 5 per cent level = 0.163

** Significant at 1 per cent level = 0.213

Table 4.7: Correlation matrix for some selected soil characters at 15-30 cm depth.

	pH	ECe	CEC	ESP	Na⁺	ESI	OC	Ca²⁺	Mg²⁺	CO₃²⁻	HCO₃⁻	Cl⁻
ECe	0.592**											
CEC	0.186*	0.216**										
ESP	0.758**	0.666**	0.142									
Na⁺	0.749**	0.678**	0.380**	0.952**								
ESI	-0.372**	0.131	0.021	-0.426**	-0.375**							
OC	-0.578**	-0.128	0.126	-0.263**	-0.247**	0.190*						
Ca²⁺	-0.126	-0.035	0.665**	-0.188*	-0.013	0.265**	0.286**					
Mg²⁺	-0.227**	-0.229**	0.409**	-0.403**	-0.288**	0.060	0.076	-0.125				
CO₃⁻	0.626**	0.520**	0.181*	0.739**	0.749**	-0.161	-0.269**	0.056	-0.450**			
HCO₃²⁻	0.379**	0.357**	0.036	0.448**	0.395**	-0.158	0.025	-0.070	-0.214**	0.203*		
Cl⁻	0.309**	0.393**	0.143	0.374**	0.387**	0.023	-0.192*	0.083	-0.214**	0.380**	-0.033	
SO₄²⁻	-0.134	0.242**	0.083	0.238**	0.206*	0.032	0.365**	0.118	-0.193*	0.200*	0.179*	0.033

• * Significant at 5 per cent level = 0.163

** Significant at 1 per cent level = 0.213

Table 4.8: Physical properties of selected soil profiles in salt affected soils of site 1.

Profile number	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural Class	BD (Mg m⁻³)	WHC (%)
Profile- 1	0-15	64.3	11.3	23.5	SCL	1.30	35.9
	15-50	41.3	20.8	37.3	CL	1.32	40.1
	50-83	49.6	14.3	35.5	SCL	1.32	41.1
	83-115	50.3	15.5	33.3	SCL	1.36	39.0
	115-140	67.9	6.5	24.8	SCL	1.44	37.4
Profile- 2	0-18	58.5	14.0	26.8	SCL	1.33	36.0
	18-29	43.1	13.5	42.5	C	1.36	48.5
	29-66	38.3	27.0	34.3	CL	1.47	45.2
	66-102	57.3	7.0	35.0	SC	1.54	41.5
	102-140	63.5	11.0	24.8	SCL	1.57	35.8

observed in the last horizon (6.5 per cent). The clay content ranged from 23.5 to 37.3 per cent. The maximum was observed in second horizon (15-50 cm) and minimum in the first horizon. The textural class was sandy clay loam in all the horizons except second horizon (clay loam).

In profile 2 (P₂), the sand content of the surface horizon was 58.5 per cent and in subsurface horizons it varied from 38.3 to 63.5 per cent. Maximum was observed in fifth horizon (102-140 cm) and least in the third horizon (29-66 cm). The silt content ranged between 7.0 to 27.0 per cent. The clay content ranged from 24.8 to 42.5 per cent. Maximum was observed in the second horizon (18-29 cm) and the least was in fifth horizon (102-140 cm). The textural class was sandy clay loam in first and fifth horizons, clay in second horizon and clay loam in third horizon and sandy clay in fourth horizon.

Bulk density of soil varied from 1.30 to 1.44 Mg m⁻³ in P₁ and 1.33 to 1.57 Mg m⁻³ in P₂. The bulk density of the soil increased with depth in both the profiles. Water holding capacity of soil in profiles ranged from 35.9 to 41.1 and 35.8 to 48.5 per cent in P₁ and P₂, respectively.

4.5.1.2 Site 2

In profile P₃, the total sand content ranged from 62.9 to 77.9 per cent (Table 4.9). The maximum was observed in the fifth horizon (90-120 cm) and the least was in the third horizon (25-60 cm). The total silt content did not show any particular trend in the profile and was found maximum in the last horizon (5.0 per cent). The clay content ranged from 16.5 to 32.5 per cent with the maximum in the third horizon (25-60 cm) and minimum in the last horizon. The textural class of the soil was sandy clay loam in all horizons except last horizon which was sandy loam.

The total sand content of the P₄ varied from 26.5 to 39.4 per cent. The maximum value was observed in the fourth horizon (60-90 cm) and least was in the third horizon (30-60 cm). The total silt content of soil profile has increased with depth up to third horizon and then decreased. The silt content of pedon varied from 13.0 per cent (surface horizon) to 27.8 per cent (third horizon). The clay content ranged from 40.3 to 49.5 per cent. The clay content has decreased with the depth from first to fourth horizon and has

Table 4.9: Physical properties of selected soil profiles in salt affected soils of site 2.

Profile number	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class	BD (Mg m⁻³)	WHC (%)
Profile- 3	0-11	69.1	4.5	25.8	SCL	1.34	34.0
	11-25	68.5	3.5	27.1	SCL	1.40	34.3
	25-60	62.9	4.1	32.5	SCL	1.42	34.8
	60-90	70.2	1.8	27.3	SCL	1.45	32.4
	90-120	77.9	5.0	16.5	SL	1.52	27.0
Profile- 4	0-10	36.6	13.0	49.5	C	1.28	55.0
	10-30	37.9	16.0	45.3	C	1.33	53.5
	30-60	26.5	27.8	44.8	C	1.35	51.6
	60-90	39.4	19.5	40.3	C	1.35	50.4
	90-120	35.8	15.5	48.0	C	1.38	54.1

increased in the fifth horizon (48.0 per cent). The textural class of the soil was clay in all the horizons.

The bulk density of soil varied from 1.34 to 1.52 and 1.28 to 1.38 Mg m⁻³ in P₃ and P₄. The BD has increased with depth whereas, WHC decreased with the depth except last layer in P₄ and it varied between 27.0 to 34.8 Mg m⁻³ in P₃ and 50.4 to 55.0 per cent in P₄.

4.5.1.3 Site 3

In P₅, the sand content has increased with depth and the silt content has decreased with depth of the profile (Table 4.10). The sand content ranged from 59.9 to 91.0 per cent. The minimum value was observed in surface horizon (0-20 cm) and maximum value was in the fourth horizon (80-110 cm). The silt content of first horizon was 21.8 per cent and it decreased with depth to 7.3 per cent in the last horizon. The clay content ranged from 1.5 to 22.8 per cent. The maximum was observed in the second horizon (20-50 cm) and the least in the fourth horizon (80-110 cm). The textural class of the soils was sandy clay loam in the first two horizons, loamy sand and sand in the third and fourth horizons.

The sand content of the profile P₆ varied from 39.0 to 64.4 per cent. The maximum value was observed in the last horizon (90-120 cm) and least was in the second horizon. The silt content did not show any particular trend of variation in the profile and was found maximum in the second horizon (24.8 per cent) and least was in the first horizon (9.8 per cent). The clay content ranged from 18.5 to 35.8 per cent. The maximum was observed in the second horizon and the least was in the last horizon. The textural class of the soils was sandy clay loam in the first four horizons and sandy loam in the fifth horizon.

In profile P₇, the total sand content ranged from 49.0 to 71.6 per cent and it did not show any particular trend vertically. The highest value was observed in the first horizon (0-23 cm) and least was in the fourth horizon (68-76 cm). The silt content ranged from 6.0 to 15.0 per cent and was found maximum in the third horizon (52-68 cm) the least was in the surface horizon. The clay content ranged from 21.8 to 36.0 per cent. The

Table 4.10: Physical properties of selected soil profiles in salt affected soils of site 3.

Profile number	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural Class	BD (Mg m⁻³)	WHC (%)
Profile- 5	0-20	59.9	17.5	21.8	SCL	1.37	40.2
	20-50	66.4	10.3	22.8	SCL	1.41	35.1
	50-80	80.8	10.3	8.0	LS	1.56	24.9
	80-110	91.0	7.3	1.5	S	1.67	20.1
Profile- 6	0-18	60.8	9.8	29.0	SCL	1.19	44.7
	18-32	39.0	24.8	35.8	SCL	1.26	48.6
	32-55	59.4	17.3	22.8	SCL	1.31	43.8
	55-90	63.3	14.5	21.3	SCL	1.35	41.3
	90-120	64.4	16.3	18.5	SL	1.40	36.9
Profile-7	0-23	71.6	6.0	21.8	SCL	1.23	40.9
	23-52	50.6	13.8	34.8	SCL	1.29	44.3
	52-68	58.1	15.0	26.1	SCL	1.33	41.3
	68-76	49.0	14.1	36.0	SC	1.36	43.1
	76-120	61.1	8.3	30.0	SCL	1.61	39.4

maximum value was observed in the fourth horizon and the least was in the first horizon. The texture of the soils was sandy clay loam except the fourth horizon (sandy clay).

Bulk density of the profiles varied from 1.37 to 1.67, 1.19 to 1.40, 1.23 to 1.61 Mg m^{-3} in P_4 , P_6 and P_7 , respectively. It increased with depth in all the profiles. The WHC has decreased with the depth except in second layer of P_6 and P_7 and it varied from 20.1 to 40.2, 36.9 to 48.6 and 39.4 to 44.3 per cent in P_5 , P_6 and P_7 , respectively.

4.5.1.4 Site 4

The total sand content of the profile P_8 varied from 36.7 to 65.4 per cent (Table 4.11). The maximum value was observed in the last horizon (90-115 cm) and least was in the second horizon (25-44 cm). The silt content was found maximum in the second horizon (17.3 per cent). The clay content ranged from 27.3 to 45.3 per cent. The maximum value was observed in the last horizon and the least was in the second horizon. The textural class of the soil was sandy clay in the first, third and fourth horizons. Second horizon had clay texture and the fifth horizon was sandy clay loam texture.

In P_9 , the sand content ranged from 37.5 to 56.0 per cent. The maximum was observed in last horizon and least was in the second horizon (20-45 cm). The least silt content was found in surface (6.8 per cent) and maximum in the second horizon (10.0 per cent). The clay content in surface soil was 40.5 per cent and it ranged from 51.8 to 35.8 per cent from second to last layer. The textural class of the soil was clay in the second horizon and it was sandy clay in the first, third and fourth horizon.

The sand content of the profile P_{10} varied from 35.8 to 59.6 per cent. The maximum value was observed in the surface horizon and least was in the third horizon (30-60 cm). The silt content was found maximum in third horizon (16.5 per cent) and the least was in the fourth horizon (10.8 per cent). The clay content ranged from 26.8 to 48.3 per cent. The maximum value was observed in the fourth horizon (60-90 cm) and the least was in the second horizon. The textural class of the fine earth was sandy clay loam in the first and second horizons, clay in the third and forth horizons and clay loam in the last horizon.

Table 4.11: Physical properties of selected soil profiles in salt affected soils of site 4.

Profile number	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class	BD (Mg m⁻³)	WHC (%)
Profile- 8	0-25	48.6	14.5	36.3	SC	1.12	48.6
	25-44	36.7	17.3	45.3	C	1.15	54.0
	44-60	45.5	8.8	45.0	SC	1.25	49.7
	60-90	50.3	9.0	39.8	SC	1.31	48.2
	90-115	65.4	6.8	27.3	SCL	1.47	45.3
Profile- 9	0-20	51.8	6.8	40.5	SC	1.20	48.6
	20-45	37.5	10.0	51.8	C	1.18	56.0
	45-72	45.9	8.1	45.5	SC	1.28	51.2
	72-110	56.0	7.5	35.8	SC	1.40	48.3
Profile-10	0-15	59.6	12.0	27.8	SCL	1.25	37.1
	15-30	56.9	15.5	26.8	SCL	1.29	35.8
	30-60	35.8	16.5	47.0	C	1.28	52.4
	60-90	40.0	10.8	48.3	C	1.29	50.8
	90-120	44.5	19.5	35.3	CL	1.34	46.5
Profile-11	0-15	85.6	8.5	5.0	LS	1.77	21.7
	15-70	93.0	3.8	2.8	S	1.85	20.6
	70-110	42.4	15.5	41.5	C	1.35	44.6

In P₁₁, the total sand content ranged from 42.4 to 93.0 per cent. The maximum value was observed in the second horizon (15-70 cm) and least was in the third horizon (70-110 cm). The silt content was found maximum in the third horizon (15.5 per cent). The clay content ranged from 2.8 to 41.5 per cent. The maximum value was observed in the third horizon (70-110 cm) and the least was in the second horizon. The textural class of the soils was loamy sand, sand and clay in the surface and subsurface horizons.

Bulk density values ranged from 1.12 to 1.47 Mg m⁻³ in P₈, from 1.18 to 1.40 Mg m⁻³ in P₉, from 1.25 to 1.34 in P₁₀ and 1.35 to 1.85 in P₁₁. The WHC did not show any trend with the depth and it varied between 45.3 to 54.0 per cent in P₈, from 48.3 to 56.0 in P₉, from 35.8 to 52.4 in P₁₀ and 20.6 to 44.6 in P₁₁.

4.5.2 Chemical characteristics of profiles

4.5.2.1 Soil reaction (pH)

The data pertaining to pH of eleven profiles studied are given in Tables 4.12 to 4.15. The pH of the soils (1:2.5 soil: water suspension) ranged from 8.3 to 10.4 and it was moderate to very strongly alkaline in reaction.

In site 1 the soil reaction is very strongly alkaline in both the profiles. In P₁ the pH values in the surface horizon was 9.1 and in the subsoil it ranged from 9.5 to 9.8 (Table 4.12). Highest pH value was observed in second horizon (15-50 cm). In P₂, the pH values ranged from 9.2 to 9.9. The highest value was observed in second and last horizons.

In site 2 the pH of all horizons was strongly alkaline to very strongly alkaline. In P₃ the pH value ranged from 9.2 to 10.3. The highest pH was observed in second horizon and lowest was observed in the last horizon (Table 4.13). In P₄, the pH value ranged from 8.6 to 9.3. The highest pH was observed in first horizon and lowest was observed in the last horizon and it decreased with the increasing depth of the profile.

The pH of P₅ (site 3) ranged from 8.3 to 8.6 (Table 4.14). The highest value was recorded in the third horizon and the lowest value was recorded in the last horizon. In P₆, the pH ranged from 8.9 to 9.4. The highest was recorded in the first horizon and the

Table 4.12: Chemical properties of selected soil profiles in salt affected soils of site 1.

Profile number	Depth (cm)	pH (1:2.5)	ECe (d Sm ⁻¹)	OC (g kg ⁻¹)	CaCO ₃ (%)	Exchangeable cations [cmol(p ⁺)kg ⁻¹]				CEC [cmol (p ⁺)kg ⁻¹]	ESP	Ca:Mg	Ca:Na	ESI
						Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺					
Profile- 1	0-15	9.1	3.3	3.6	2.8	6.0	4.8	3.7	0.28	19.1	19.5	1.3	1.6	0.03
	15-50	9.8	4.6	2.0	1.7	9.0	3.0	7.8	0.32	28.0	27.8	3.0	1.2	0.06
	50-83	9.6	5.6	1.7	0.7	7.0	6.8	7.1	0.34	35.2	20.2	1.0	1.0	0.06
	83-115	9.6	5.2	1.4	0.2	7.4	6.4	6.6	0.31	26.7	24.8	1.2	1.1	0.05
	115-140	9.5	2.9	1.3	1.3	5.6	5.4	5.0	0.24	25.8	19.4	1.0	1.1	0.03
Profile- 2	0-18	9.2	7.4	6.2	5.2	12.0	4.2	5.4	0.43	28.7	18.7	2.9	2.2	0.07
	18-29	9.9	6.3	2.0	4.0	6.6	4.2	9.7	0.26	42.0	23.2	1.6	0.7	0.08
	29-66	9.7	3.0	1.8	1.7	11.2	4.0	8.4	0.28	31.6	26.6	2.8	1.3	0.04
	66-102	9.7	4.5	1.3	1.8	9.2	5.2	6.9	0.27	31.7	21.7	1.8	1.3	0.03
	102-140	9.9	4.1	1.1	2.5	7.2	3.6	6.9	0.22	28.3	24.2	2.0	1.1	0.03

Table 4.13: Chemical properties of selected soil profiles in salt affected soils of site 2.

Profile number	Depth (cm)	pH	ECe dSm ⁻¹	OC (g kg ⁻¹)	CaCO ₃ (%)	Exchangeable cations (cmol(p ⁺)kg ⁻¹)				CEC (cmol (p ⁺)kg ⁻¹)	ESP	Ca: Mg	Ca: Na	ESI
						Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺					
Profile- 3	0-11	9.6	7.9	4.5	0.8	5.0	4.0	5.4	0.25	14.3	37.7	1.3	0.9	0.03
	11-25	10.3	10.3	1.0	1.3	6.8	5.4	7.8	0.23	20.5	37.9	1.3	0.9	0.05
	25-60	10.1	9.1	1.1	0.9	4.6	4.2	6.8	0.22	19.6	34.4	1.1	0.7	0.04
	60-90	9.9	6.6	1.0	0.6	5.6	5.2	5.2	0.20	13.3	38.7	1.1	1.1	0.03
	90-120	9.2	2.3	0.7	0.5	4.8	3.8	1.4	0.17	10.2	13.2	1.3	3.6	0.02
Profile- 4	0-10	9.3	2.3	1.3	1.0	11.4	10.6	5.1	0.24	42.4	12.0	1.1	2.2	0.05
	10-30	9.1	1.3	1.0	0.6	11.6	10.6	3.6	0.22	47.6	7.5	1.1	3.2	0.04
	30-60	8.9	1.2	1.0	0.7	9.6	8.4	3.3	0.30	61.9	5.4	1.1	2.9	0.06
	60-90	8.8	1.1	0.7	0.6	5.4	5.6	2.8	0.29	48.2	5.8	1.0	1.9	0.05
	90-120	8.6	0.8	0.6	0.5	6.4	6.0	1.9	0.34	50.1	3.9	1.1	3.3	0.05

Table 4.14: Chemical properties of selected soil profiles in salt affected soils of site 3.

Profile number	Depth (cm)	pH (1:2.5)	ECe dSm ⁻¹	OC (g kg ⁻¹)	CaCO ₃ (%)	Exchangeable cations (cmol(p ⁺)kg ⁻¹)				CEC (cmol (p ⁺)kg ⁻¹)	ESP	Ca:Mg	Ca:Na	ESI
						Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺					
Profile- 5	0-20	8.5	1.5	5.7	0.7	13.0	7.0	0.6	0.24	32.9	1.8	1.9	22.0	0.14
	20-50	8.3	0.9	2.0	-	7.0	6.0	1.1	0.22	31.1	3.5	1.2	6.4	0.04
	50-80	8.6	0.8	1.3	-	4.4	3.6	0.6	0.14	14.4	4.0	1.2	7.7	0.03
	80-110	8.5	1.0	0.7	-	2.6	1.6	0.3	0.12	6.3	5.0	1.6	8.3	0.01
Profile- 6	0-18	9.4	5.0	5.6	3.2	10.4	7.6	4.6	0.28	34.0	13.5	1.4	2.3	0.06
	18-32	9.0	3.3	2.2	3.1	14.0	13.4	4.1	0.25	46.5	8.9	1.0	3.4	0.08
	32-55	9.1	2.1	1.3	2.3	12.6	11.4	2.4	0.25	37.2	6.4	1.1	5.3	0.06
	55-90	9.0	1.8	1.3	2.0	11.4	10.0	2.0	0.24	33.9	6.0	1.1	5.6	0.05
	90-120	8.9	2.3	0.6	1.1	10.8	10.0	1.8	0.25	29.5	5.9	1.1	6.2	0.05
Profile-7	0-23	9.2	2.1	3.1	0.6	4.6	4.4	2.1	0.21	20.4	10.2	1.0	2.2	0.03
	23-52	8.8	2.6	3.1	2.8	7.2	6.0	1.9	0.29	37.5	4.9	1.2	3.9	0.09
	52-68	8.8	2.0	2.7	0.8	7.8	7.4	1.3	0.22	26.6	5.0	1.1	5.9	0.07
	68-76	8.8	1.7	2.0	0.9	8.6	7.6	1.7	0.24	41.1	4.2	1.1	5.0	0.07
	76-120	8.6	1.6	1.3	0.8	5.6	5.4	1.4	0.19	32.5	4.4	1.0	3.9	0.06

lowest was recorded in the last horizon. In P₇, the value of pH ranged from 8.6 to 9.2. The highest was recorded in the surface horizon and the lowest was recorded in the last horizon.

In site 4, all the horizons in P₈ were very strongly alkaline in nature. The pH ranged from 9.5 to 9.8 (Table 4.15). The highest was recorded in the third horizon and the lowest was recorded in the surface horizon. In P₉, the value of pH ranged from 10.1 to 10.3. The highest was recorded in the second horizon and lowest was recorded in the third and fourth horizon. In P₁₀, the pH ranged from 9.4 to 10.2 (Table 4.15). The highest value was observed in the surface horizon and the lowest was recorded in the last horizon. In P₁₁, the pH ranged from 9.7 to 10.4. The highest was observed in the surface horizon and lowest in the last horizon. The soils were very strongly alkaline in nature.

Soil pH did not follow any definite trend in the profile samples except P₁₀ wherein the pH decreased gradually with depth. Higher soil pH was recorded in the second depth in most cases and then decreased with depth.

4.5.2.2 Electrical conductivity (ECe)

The values of ECe ranged from 0.8 to 10.3 dS m⁻¹ (Tables 4.12 to 4.15). The data indicated that the ECe in P₁ ranged from 2.9 to 5.6 dS m⁻¹ and in P₂ it ranged from 3.0 to 7.4 dS m⁻¹, in P₃ the values ranged from 2.3 to 10.3 dS m⁻¹, in P₄ it ranged from 0.8 to 2.3 dS m⁻¹ and the ECe decreased with depth in P₄. In site 3, the ECe values ranged from 0.8 to 1.5 dS m⁻¹ in P₅, 1.8 to 5.0 dS m⁻¹ in P₆, from 1.6 to 2.6 dS m⁻¹ in P₇. The ECe values of P₈ in site 4 ranged from 2.4 to 8.1 dS m⁻¹, from 2.3 to 9.8 dS m⁻¹ in P₉, from 3.7 to 9.5 dS m⁻¹ in P₁₀ and from 2.3 to 6.9 dS m⁻¹ in P₁₁.

The ECe value in general decreased with depth in the profiles of site 3, while in other sites it did not follow definite trend.

4.5.2.3 Organic carbon

The data pertaining to organic carbon content of the profiles studied are presented in Tables 4.12 to 4.15.

Table 4.15: Chemical properties of selected soil profiles in salt affected soils of site 4.

Profile number	Depth (cm)	pH (1:2.5)	ECe dSm ⁻¹	OC (g kg ⁻¹)	CaCO ₃ (%)	Exchangeable cations (cmol(p ⁺)kg ⁻¹)				CEC (cmol (p ⁺)kg ⁻¹)	ESP	Ca: Mg	Ca: Na	ESI
						Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺					
Profile- 8	0-25	9.5	3.5	2.9	3.3	14.6	6.4	7.8	0.29	35.7	21.7	2.3	1.9	0.04
	25-44	9.7	2.4	1.9	3.3	14.4	6.2	9.9	0.18	48.0	20.5	2.3	1.5	0.04
	44-60	9.8	4.3	0.7	1.4	9.8	5.4	9.8	0.17	44.4	22.1	1.8	1.0	0.05
	60-90	9.7	8.1	0.3	0.6	7.4	6.6	9.0	0.15	34.6	26.0	1.1	0.8	0.08
	90-115	9.7	3.8	0.1	0.5	6.4	4.8	7.4	0.13	28.0	26.4	1.3	0.9	0.03
Profile- 9	0-20	10.2	3.7	2.2	3.7	7.2	3.8	9.7	0.16	38.3	25.3	1.9	0.7	0.04
	20-45	10.3	2.3	1.2	5.0	4.2	5.8	11.8	0.14	45.6	25.9	0.7	0.4	0.04
	45-72	10.1	9.7	0.3	2.3	7.2	3.8	10.5	0.12	32.8	31.9	1.9	0.7	0.10
	72-110	10.1	9.8	0.1	0.8	6.6	2.8	8.3	0.14	39.9	20.9	2.4	0.8	0.10
Profile-10	0-15	10.2	5.3	2.0	1.5	12.0	2.8	6.5	0.19	31.8	20.5	1.5	1.8	0.04
	15-30	10.0	9.5	0.6	1.3	7.4	5.6	7.7	0.17	37.9	20.3	1.3	1.0	0.10
	30-60	9.8	5.2	0.4	0.5	7.0	4.4	8.9	0.18	36.8	24.3	1.6	0.8	0.08
	60-90	9.5	4.2	0.1	0.8	4.4	3.6	8.2	0.18	34.2	24.1	1.2	0.5	0.07
	90-120	9.4	3.7	0.1	1.2	4.2	3.2	7.0	0.20	27.4	25.5	1.3	0.6	0.06
Profile-11	0-15	10.4	6.9	0.3	1.6	2.0	1.8	4.2	0.07	9.0	46.9	1.1	0.5	0.02
	15-70	9.9	2.7	0.1	0.3	1.2	0.7	0.6	0.03	4.1	15.6	1.7	1.9	0.01
	70-110	9.7	2.3	0.3	0.6	7.2	6.6	6.7	0.18	30.7	13.2	1.1	1.1	0.04

The organic carbon content of soil decreased with depth in all the profiles. In site 1 the organic carbon value of P₁ and P₂ in the surface horizon ranged from 3.6 and 6.2 g kg⁻¹ and in the subsurface soil horizons it ranged from 1.3 to 2.0 and 1.1 to 2.0 g kg⁻¹, respectively (Table 4.12).

The organic carbon value of site 2 in the surface horizon of P₃ was 4.5 g kg⁻¹ and in the subsoil horizons it ranged from 0.7 to 1.1 g kg⁻¹ (Table 4.13). The highest value was observed in surface horizon and least was in the fourth horizon. In P₄ the organic carbon value of the surface horizon was 1.3 g kg⁻¹ and in the subsoil it ranged from 0.6 to 1.0 g kg⁻¹. The organic carbon values decreased with the depth in this profile. The maximum was observed in surface horizon and least in the last horizon.

In site 3, the organic carbon value of the surface horizon of P₅ was 5.7 g kg⁻¹ and in the subsoil it ranged from 0.7 to 2.0 g kg⁻¹ (Table 4.14). In P₆ the organic carbon value of the surface horizon was 5.6 g kg⁻¹ and in the subsoil it ranged from 0.6 to 2.2 g kg⁻¹. In P₇ the organic carbon value of the surface horizon was 3.1 g kg⁻¹ and in the subsoil it ranged from 1.3 to 3.1 g kg⁻¹.

The organic carbon content of surface horizons of all the profiles (P₈, P₉, P₁₀ and P₁₁) in site four was 2.9, 2.2, 2.0 and 0.3 g kg⁻¹, respectively and in the subsoil, it ranged from 0.1 to 1.9, 0.1 to 1.2, 0.1 to 0.6 and 0.1 and 0.3 g kg⁻¹, respectively (Table 4.15).

4.5.2.4 Free calcium carbonate

The free calcium carbonate content in the profiles (P₁ and P₂) of site one has decreased with depth except in the last horizon and it varied from 0.2 to 2.8 and 1.7 to 5.2 per cent, respectively (Table 4.12). Similarly it varied from 0.5 to 1.3 and 0.5 to 1.0 per cent in different horizons of profiles P₃ and P₄ of site 2 and it decreased from first to last horizon in both the profiles with a tendency to decrease with depth (Table 4.13).

The profiles P₅, P₆ and P₇ of site 3 had the free CaCO₃ content in the range of the traces to 0.7, 1.1 to 3.2 and 0.6 to 2.8 per cent, respectively. While it ranged from 0.5 to 3.3, 0.8 to 5.0, 0.5 to 1.5 and 0.3 to 1.6 per cent in the P₈, P₉, P₁₀ and P₁₁, respectively in

site 4. The CaCO_3 content decreased with depth in all the profiles except in P_9 where the second horizon had the higher calcium carbonate content.

4.5.2.5 Exchangeable cations

The results on the exchangeable cations like calcium, magnesium, sodium, potassium, cation exchange capacity and exchangeable sodium percentage (ESP) of the profile samples studied are presented in Tables 4.12 to 4.15.

Among the exchangeable cations studied, calcium, magnesium and sodium were the dominant cations in the profile samples of site 1, 2 and 4, while calcium and magnesium were the dominant cations in site 3.

4.5.2.5.1 Exchangeable calcium

The exchangeable calcium content of soil has varied with depth. The maximum content of exch. Ca was observed in first and second horizons of all the profiles. In site 1 and 2, exch. Ca was unevenly distributed and ranged from 5.6 to 9.0, 7.2 to 12.0, 4.6 to 6.8 and 5.4 to 11.6 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ in P_1 , P_2 , P_3 and P_4 , respectively.

In site 3, the exch. Ca content of P_5 and P_6 has decreased with depth, whereas in P_7 it increased. It ranged from 2.6 to 13.0, 10.4 to 14.8 and 5.6 to 8.6 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$, respectively. The exch. Ca content of P_8 and P_{10} has decreased with depth from 14.6 to 6.4 and 12.0 to 4.2 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$. In P_9 and P_{11} it is irregularly distributed and it ranged from 4.2 to 7.2 and 1.2 to 7.2 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$, respectively.

4.5.2.5.2 Exchangeable magnesium

The exchangeable magnesium (exch. Mg) content of P_1 and P_2 ranged from 3.0 to 6.8 and 3.6 to 5.2 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$, respectively and it decreased with the depth, where as in P_3 and P_4 the distribution was irregular and ranged from 3.8 to 5.4 and 5.6 to 10.6 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$, respectively.

In site 3, the exch. Mg content has decreased with depth and in P_5 and P_6 and there was no definite trend in P_7 . It varied from 1.6 to 7.0, 7.6 to 13.4 and 4.4 to 7.6 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil, respectively. The exch. Mg content of P_9 and P_{10} has decreased with depth

from second horizon to last horizon (2.8 to 5.8 and 3.2 to 5.6 cmol (p⁺) kg⁻¹, respectively), whereas in P₈ and P₁₁ the distribution was uneven with the depth. It ranged from 4.8 to 6.6 and 0.7 to 6.6 cmol (p⁺) kg⁻¹ in P₈ and P₁₁, respectively.

4.5.2.5.3 Exchangeable sodium

The exchangeable sodium content of soil has decreased with depth in all the profiles studied except in the P₇, P₁₀ and P₁₁ wherein irregular distribution was observed. In P₁, P₂, P₃, P₅, P₈ and P₉ it was highest in the second horizon and then it decreased with the depth. The exch. Na content of P₁ and P₂ ranged between 3.7 to 7.8 and 5.4 to 9.7 cmol (p⁺) kg⁻¹, respectively. Minimum was observed in first horizon of both the profiles. In P₃ and P₄, the exch. Na content of soil ranged from 1.4 to 7.8 and 1.9 to 5.1 cmol (p⁺) kg⁻¹, respectively.

In site 3, the exch. Na content of soil was low. It ranged from 0.3 to 1.1, 1.8 to 4.6 and 1.3 to 7.1 cmol(p⁺)kg⁻¹ in P₅, P₆ and P₇, respectively. In site 4, the exchangeable sodium was high in the second horizon in P₈, P₉ and up to third horizon in P₁₀ with irregular distribution in P₁₁. It ranged from 7.8 to 9.9, 8.3 to 11.8, 6.5 to 8.9 and 0.6 to 6.7 cmol(p⁺)kg⁻¹ in P₈, P₉, P₁₀ and P₁₁, respectively.

4.5.2.5.4 Exchangeable potassium

The exch. potassium was the least dominating cation in soil at all the depths. In general the exch. K content of soil has decreased with depth in all the profiles except P₄, P₁₀ and P₁₁ with irregular distribution. The exch. K content of soil ranged from 0.22 to 0.43 cmol(p⁺)kg⁻¹ in site one, 0.17 to 0.34 cmol(p⁺)kg⁻¹ in site two, 0.12 to 0.29 cmol(p⁺)kg⁻¹ in site three and 0.03 to 0.29 cmol(p⁺)kg⁻¹ in site four.

4.5.2.6 Cation exchange capacity

The cation exchange capacity of soil of P₁ has increased with depth up to third horizon and then it decreased, whereas in P₂ and P₃ the CEC has increased up to second horizon and then it decreased (Tables 4.12 to 4.15). It varied from 19.1 to 35.2, 28.3 to 42.0 and 10.2 to 20.5 cmol(p⁺)kg⁻¹ in P₁, P₂ and P₃, respectively. The CEC of P₄ ranged from 42.4 to 61.9 cmol(p⁺)kg⁻¹ and it was irregularly distributed with depth.

In P₅, the CEC of soil has decreased with depth from 32.9 to 6.3 cmol(p⁺)kg⁻¹. The CEC of surface horizon in P₆ was 34.0 cmol(p⁺)kg⁻¹ and it ranged from 46.5 to 29.5 cmol(p⁺)kg⁻¹ and it decreased from the second horizon, whereas the CEC of P₇ was irregularly distributed with the depth and it ranged from 20.4 cmol(p⁺)kg⁻¹ in surface horizon to 41.1 cmol(p⁺)kg⁻¹ in fourth horizon.

Higher CEC values were recorded in second horizon of P₈, P₉ and P₁₀ and then decreased with the depth. The CEC of P₈, P₉, P₁₀ and in surface horizon was 35.7, 38.3, 31.8 and 9.0 cmol(p⁺)kg⁻¹ and in subsurface horizon it ranged from 28.0 to 48.0, 32.8 to 45.6, 27.4 to 37.9 and 4.1 to 30.7 cmol(p⁺)kg⁻¹, respectively.

4.5.2.7 Exchangeable sodium percentage (ESP)

The ESP values ranged from 19.4 to 27.8 and 18.7 to 26.6 in P₁ and P₂ and it did not show any particular trend with depth in both the profiles (Tables 4.12 to 4.15). Whereas the ESP value has decreased with depth in P₃ and P₄, it ranged from 13.2 to 38.7 in P₃ and 3.9 to 12.0 in P₄.

The ESP values of P₅ has increased with depth from 1.8 to 5.0 and in P₆ and P₇, it decreased with depth from 13.5 to 5.9 and 10.2 to 4.2 in all the horizons. In site 4, the ESP of soil has increased with depth in the P₈, P₉ and P₁₀ except P₁₁, where it decreased with the depth. The ESP value of P₈, P₉, P₁₀ and P₁₁ ranged from 20.5 to 26.4, 20.9 to 31.9, 20.3 to 25.5 and 13.2 to 46.9, respectively.

4.5.2.8 Ca: Mg, Ca: Na and ESI of soils

The Ca: Mg ratio ranged from 1.0 to 3.0 in P₁ and 1.6 to 2.9 in P₂. The Ca: Na ratio varied between 1.0 to 1.6 in P₁ and from 0.7 to 2.2 in P₂ (Tables 4.12 to 4.15). The higher values of Ca: Na was observed in first layer of profiles than the other layers. The ESI value ranged between 0.03 to 0.06 and 0.03 to 0.08 in P₁ and P₂, respectively.

The Ca: Mg ratio ranged from 1.0 to 1.3; the Ca: Mg values of both P₃ and P₄ were more or less same. The Ca: Na ratio varied from 0.7 to 3.6 in P₃ and 1.9 to 3.3 in P₄. The ESI values ranged between 0.02 to 0.05 and 0.04 to 0.06 in P₃ and P₄, respectively. The Ca: Mg, Ca: Na ratio and ESI were irregular in distribution in all the profiles of site

3. The ESI values ranged from 1.0 to 1.9, 2.2 to 22.0 and 0.01 to 0.14, respectively (P_5 , P_6 and P_7).

In site 4, the Ca: Mg ratio varied between 0.7 to 2.4 and Ca: Na ratio varied from 0.4 to 1.9. The ESI varied from 0.01 to 0.10. The ESI has increased with increase in depth indicating the surface soil layer is highly degraded by sodium (Table 4.15).

4.5.3 Composition of soluble cations

Sodium was the dominant ion among the soluble cations studied followed by potassium, calcium and magnesium. The results are presented in Tables 4.16 to 4.19.

4.5.3.1 Calcium

The soluble calcium content did not vary much between the profiles and also with depths in all the four sites studied, but all the profiles showed slight decrease in calcium content with increase in depth except P_{11} . The calcium content of soil ranged from 0.52 to 1.90 in site 1, 0.42 to 0.92 me L^{-1} in site 2, 0.54 to 1.08 me L^{-1} in site 3 and 0.36 to 0.90 me L^{-1} in site 4.

4.5.3.2 Magnesium

The soluble magnesium content followed the same trend as that of soluble calcium. The magnesium content of soil has decreased with depth from 0.18 to 1.02 me L^{-1} in site one, from 0.18 to 0.72 me L^{-1} in site two, from 0.12 to 0.66 me L^{-1} in site three and from 0.18 to 0.36 me L^{-1} in site four.

4.5.3.3 Sodium

The soluble sodium content of soil has increased with depth up to second and third horizons and then decreased in P_1 , P_2 , P_3 , P_8 and P_9 . Whereas the soluble sodium content of soil has decreased with depth in P_4 , P_5 , P_6 , P_7 and P_{10} except P_{11} where higher sodium content was noticed in last horizon (7.29 me L^{-1}). The soluble sodium in profiles of site one ranged from 4.73 to 7.53, 4.83 to 11.67 me L^{-1} and in site two it ranged from 3.22 to 13.25 and 1.83 to 5.84 me L^{-1} , respectively.

Table 4.16: Water soluble cations and anions content of selected soil profiles in salt affected soils of site 1.

Profile number	Depth (cm)	Water soluble cations (me L ⁻¹)				Water soluble anions (me L ⁻¹)			
		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	CO ₃ ²⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻
Profile- 1	0-15	0.72	0.54	5.63	0.27	0.90	1.98	4.50	1.30
	15-50	1.68	1.02	6.59	0.16	1.58	2.77	3.60	0.50
	50-83	0.72	0.18	7.53	0.11	1.40	1.33	3.60	1.15
	83-115	0.84	0.18	6.78	0.16	1.26	2.12	3.42	1.85
	115-140	0.54	0.54	4.73	0.18	1.32	2.42	2.24	0.95
Profile- 2	0-18	1.90	0.28	10.85	0.27	1.50	3.02	3.60	5.60
	18-29	1.08	0.18	11.67	0.13	3.06	2.44	6.50	0.40
	29-66	0.80	0.18	5.83	0.11	2.08	0.29	4.14	1.05
	66-102	0.71	0.36	6.95	0.12	1.82	2.02	3.78	1.30
	102-140	0.52	0.18	4.83	0.16	1.58	0.22	2.16	0.75

Table 4.17: Water soluble cations and anions content of selected soil profiles in salt affected soils of site 2.

Profile number	Depth (cm)	Water soluble cations (me L ⁻¹)				Water soluble anions (me L ⁻¹)			
		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	CO ₃ ²⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻
Profile- 3	0-10	0.92	0.30	9.28	0.29	1.58	2.74	2.52	2.75
	10-30	0.90	0.26	13.25	0.31	2.56	3.32	3.96	4.00
	30-60	0.72	0.22	10.18	0.32	1.40	2.76	3.60	2.55
	60-90	0.67	0.20	5.90	0.32	1.19	3.02	3.24	0.45
	90-120	0.54	0.18	3.22	0.18	1.06	0.97	1.78	1.10
Profile- 4	0-11	0.90	0.72	5.84	0.13	0.97	1.91	2.70	0.50
	11-25	0.72	0.54	3.52	0.23	0.58	1.94	3.60	0.30
	25-60	0.80	0.36	2.84	0.13	0.47	0.68	3.24	0.80
	60-90	0.58	0.28	2.90	0.14	0.54	1.30	2.06	0.55
	90-120	0.42	0.18	1.83	0.20	0.42	0.80	1.80	0.10

Table 4.18: Water soluble cations and anions content of selected soil profiles in salt affected soils of site 3.

Profile number	Depth (cm)	Water soluble cations (me L ⁻¹)				Water soluble anions (me L ⁻¹)			
		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	CO ₃ ²⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻
Profile- 5	0-20	1.08	0.38	2.75	0.27	0.72	1.33	2.06	0.50
	20-50	0.96	0.27	1.93	0.23	0.22	1.20	1.96	0.20
	50-80	0.90	0.18	1.49	0.20	0.48	0.76	1.60	0.85
	80-110	0.54	0.18	0.63	0.20	0.32	0.33	1.88	0.35
Profile- 6	0-18	0.92	0.36	7.66	0.22	1.40	3.02	3.24	0.75
	18-32	0.70	0.18	5.28	0.20	1.22	2.27	3.96	0.45
	32-55	0.62	0.16	3.34	0.22	1.30	1.40	2.78	0.35
	55-90	0.54	0.18	3.71	0.23	1.36	1.48	2.68	0.30
	90-120	0.60	0.12	1.98	0.27	0.96	1.51	0.60	0.70
Profile-7	0-23	0.90	0.66	2.99	0.20	1.58	1.19	1.70	0.95
	23-52	0.71	0.54	2.68	0.20	0.88	1.30	1.88	0.80
	52-68	0.54	0.22	3.33	0.23	0.86	1.58	2.70	0.45
	68-76	0.54	0.24	2.05	0.22	0.70	1.06	1.70	0.30
	76-120	0.62	0.18	1.43	0.32	0.58	1.12	1.60	0.20

Table 4.19: Water soluble cations and anions content of selected soil profiles in salt affected soils of site 4.

Profile number	Depth (cm)	Water soluble cations (me L ⁻¹)				Water soluble anions (me L ⁻¹)			
		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	CO ₃ ²⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻
Profile- 8	0-25	0.90	0.36	4.83	0.29	1.15	0.29	3.24	0.75
	25-44	0.72	0.28	8.01	0.23	0.94	1.26	6.32	0.30
	44-60	0.66	0.20	6.9	0.23	1.08	1.65	4.14	0.35
	60-90	0.62	0.36	7.15	0.22	1.08	1.26	4.68	0.35
	90-115	0.54	0.18	5.48	0.18	0.90	0.68	3.60	0.40
Profile- 9	0-20	0.54	0.30	7.86	0.20	1.15	1.58	4.50	0.35
	20-45	0.54	0.22	9.97	0.18	2.44	1.94	5.04	0.20
	45-72	0.72	0.18	7.65	0.16	0.97	1.37	5.94	0.15
	72-110	0.54	0.20	6.47	0.22	1.08	1.87	3.78	0.15
Profile-10	0-15	0.90	0.36	6.75	0.23	0.86	2.16	4.68	0.75
	15-30	0.72	0.32	5.96	0.22	0.90	1.62	3.42	0.40
	30-60	0.72	0.25	6.26	0.23	0.76	1.55	3.96	0.05
	60-90	0.60	0.18	7.56	0.22	0.94	0.90	4.68	0.60
	90-120	0.36	0.21	7.28	0.25	1.69	2.17	5.40	0.30
Profile-11	0-15	0.54	0.22	4.44	0.14	1.44	1.81	2.86	0.30
	15-70	0.36	0.18	3.55	0.11	-	1.08	3.68	0.25
	70-110	0.72	0.36	7.92	0.22	-	4.68	5.40	0.15

In site three, P₅ recorded lesser water soluble Na content and it ranged from 0.63 to 2.75 me L⁻¹. The soluble sodium of P₆ and P₇ ranged from 1.98 to 7.66 and 1.43 to 2.99 me L⁻¹, respectively. In site four, the soluble sodium content has increased with depth from first to second and third horizon and later it decreased in P₈, P₉ and P₁₀. It ranged from 5.48 to 8.01, 6.47 to 9.97, 5.96 to 7.56 and 3.55 to 7.92 me L⁻¹ in P₈, P₉, P₁₀ and P₁₁, respectively.

4.5.3.4 Potassium

The content of soluble potassium in site one has decreased with depth in both P₁ and P₂ except in the last horizon where a slight increase in potassium content was noticed. In first and second profiles it ranged from 0.11 to 0.27 me L⁻¹. In site two it was irregularly distributed in P₃ and P₄ and ranged from 0.13 to 0.32 me L⁻¹.

Water soluble K content of P₅ has decreased with depth where as in P₆ and P₇ it was unevenly distributed. It ranged from 0.20 to 0.32 me L⁻¹ in site three. The potassium content of P₈ and P₉ (site 3) has decreased with depth, whereas irregular distribution was noticed in P₁₀ and P₁₁. The soluble potassium content of P₈, P₉, P₁₀ and P₁₁ in site four ranged from 0.11 to 0.29 me L⁻¹.

4.5.4 Soluble anions

Among the anions studied, chlorides and bicarbonates were the dominant anions followed by sulphates and carbonates in all the profiles. The results are presented in Tables 4.16 to 4.19.

4.5.4.1 Carbonates

The carbonate content has decreased with depth in most of the profiles. But in P₁, P₂ and P₃ higher amount of carbonate content was observed in second horizon. It ranged from 0.90 to 3.06, 0.42 to 2.56, 0.22 to 1.58 and traces to 2.44 me L⁻¹ in site 1, site 2, site 3 and site 4, respectively.

4.5.4.2 Bicarbonates

The bicarbonate content of all the profiles in all the four sites studied was unevenly distributed with depth. In general the maximum content was observed in first and second horizon in most of the profiles. The bicarbonate content of site 1, 2, 3 and 4 ranged between 0.22 to 3.02, 0.68 to 3.32, 1.06 to 3.02 and 0.29 to 2.17 me L⁻¹, respectively.

4.5.4.3 Chlorides

Chloride content of soil water extract has decreased with depth in all the profiles either from the first depth or from the second depth. The chloride content ranged from 2.16 to 6.50, 1.78 to 3.96, 0.60 to 3.96 and 2.86 to 6.32 me L⁻¹ in site 1, 2, 3 and site 4, respectively.

4.5.4.4 Sulphates

Generally the soluble sulphate content of soil was more in surface layer and it decreased with depth in all the profiles with the exception in P₁, P₅ and P₇ where it was higher in the last horizons. It was higher in P₁, P₂ and P₃ and it ranged from 0.40 to 5.60 me L⁻¹ in site one, 0.10 to 4.00 me L⁻¹ in site two, 0.20 to 0.95 me L⁻¹ in site three and 0.05 to 0.75 me L⁻¹ in site four.

4.5.5 Nutrient status of the profiles

The major nutrient status of first two horizons of the salt affected soils viz., available nitrogen, phosphorus, potassium, sulphur, DTPA extractable zinc, copper, iron, manganese and hot water extractable boron content of soil are presented in Tables 4.20 to 4.23.

4.5.5.1 Available nitrogen

The available nitrogen content of soils was low in all the profiles at all the sites. The available nitrogen content varied from 37.6 to 225.8 kg ha⁻¹ in site one, from 41.4 to 238.3 kg ha⁻¹ in site two, from 67.7 to 271.0 kg ha⁻¹ in site three and 32.6 to 155.5 kg ha⁻¹

Table 4.20: Available nutrient status of selected soil profiles in salt affected soils of site 1.

Profile number	Depth (cm)	Available macronutrients (kg ha ⁻¹)			Av. S (mg kg ⁻¹)	DTPA extractable micronutrients (mg kg ⁻¹)				Boron (mg kg ⁻¹)
		N	P ₂ O ₅	K ₂ O		Zn	Cu	Fe	Mn	
Profile- 1	0-15	225.8	56.3	265.2	49.69	1.42	2.41	14.88	11.76	1.76
	15-50	96.6	17.4	297.6	23.02	0.52	1.44	3.51	09.14	1.70
	50-83	67.7	7.0	315.6	5.48	0.57	1.32	2.67	11.56	0.18
	83-115	52.7	10.3	291.6	4.75	0.38	1.30	2.54	11.10	0.12
	115-140	37.6	17.4	220.8	2.92	0.47	0.62	1.52	07.61	0.10
Profile- 2	0-18	225.8	25.8	398.4	33.11	2.16	2.99	18.22	17.50	0.40
	18-29	109.1	13.6	244.8	19.00	0.41	2.24	3.27	12.00	0.36
	29-66	85.3	15.0	261.6	8.04	0.38	1.46	2.61	06.62	0.24
	66-102	87.8	19.1	249.6	4.38	1.40	1.13	4.93	12.43	0.18
	102-140	65.2	9.4	210.0	3.29	0.37	0.45	1.62	04.76	0.16

Table 4.21: Available nutrient status of selected soil profiles in salt affected soils of site 2.

Profile number	Depth (cm)	Available macronutrients (kg ha ⁻¹)			Sulfur (mg kg ⁻¹)	DTPA extractable micronutrients (mg kg ⁻¹)				Boron (mg kg ⁻¹)
		N	P ₂ O ₅	K ₂ O		Zn	Cu	Fe	Mn	
Profile- 3	0-11	238.3	17.8	235.2	44.9	0.55	1.04	3.91	16.32	0.18
	11-25	92.8	15.5	212.4	41.3	0.71	1.72	5.75	14.40	0.96
	25-60	85.3	9.9	201.6	31.1	0.62	1.36	4.20	13.81	0.22
	60-90	66.5	7.5	186.0	26.3	0.60	0.90	4.57	8.91	0.20
	90-120	56.4	3.8	159.6	11.7	0.96	0.54	5.32	11.31	0.16
Profile- 4	0-10	94.1	14.6	224.4	4.4	0.27	0.56	3.29	2.93	0.08
	10-30	75.3	14.1	206.4	2.6	0.24	0.44	2.64	1.78	0.06
	30-60	59.0	10.3	283.2	1.5	0.30	0.43	2.86	2.28	0.06
	60-90	51.4	7.0	271.2	0.4	0.20	0.40	2.48	1.44	0.06
	90-120	41.4	5.2	318.0	0.4	0.19	0.39	2.77	1.47	0.08

Table 4.22: Available nutrient status of selected soil profiles in salt affected soils of site 3.

Profile number	Depth (cm)	Available macronutrients (kg ha ⁻¹)			Av. S (mg kg ⁻¹)	DTPA extractable micronutrients (mg kg ⁻¹)				Boron (mg kg ⁻¹)
		N	P ₂ O ₅	K ₂ O		Zn	Cu	Fe	Mn	
Profile- 5	0-20	271.0	12.2	226.8	14.3	0.34	2.06	17.21	13.70	0.46
	20-50	163.1	8.5	202.8	7.3	0.21	1.42	8.82	6.98	0.22
	50-80	91.6	9.9	129.6	3.3	0.12	0.59	3.79	2.70	0.14
	80-110	72.8	14.1	109.2	1.1	0.47	0.28	3.65	2.49	0.34
Profile- 6	0-18	260.9	10.8	258.0	21.6	0.48	2.45	7.05	11.01	0.12
	18-32	115.4	13.6	232.8	19.7	0.48	1.48	2.36	7.65	0.12
	32-55	89.1	11.7	232.8	19.0	0.22	0.50	1.74	2.01	0.14
	55-90	67.7	13.1	224.4	7.3	0.45	0.37	1.65	2.25	0.18
	90-120	67.7	13.6	236.4	3.3	0.78	0.39	2.13	3.63	0.14
Profile-7	0-23	184.4	13.6	194.4	25.9	0.22	1.61	9.29	9.16	0.26
	23-52	148.0	5.6	270.0	14.6	0.31	1.76	9.12	7.43	0.28
	52-68	125.4	13.6	204.0	6.9	0.37	1.07	6.94	6.34	0.10
	68-76	115.4	16.9	224.4	6.6	0.29	1.41	6.55	4.78	0.10
	76-120	106.6	12.7	175.2	2.6	0.23	1.27	5.31	3.24	0.10

Table 4.23: Available nutrient status of selected soil profiles in salt affected soils of site 4.

Profile number	Depth (cm)	Available macronutrients (kg ha ⁻¹)			Av. S (mg kg ⁻¹)	DTPA extractable micronutrients (mg kg ⁻¹)				Boron (mg kg ⁻¹)
		N	P ₂ O ₅	K ₂ O		Zn	Cu	Fe	Mn	
Profile- 8	0-25	155.5	13.0	272.4	30.0	0.49	2.00	10.97	11.29	0.36
	25-44	119.2	6.3	169.2	20.1	0.30	1.02	3.81	5.84	0.20
	44-60	87.8	2.5	162.0	19.0	0.39	1.02	3.91	4.95	0.14
	60-90	70.2	7.1	142.8	18.6	0.26	0.68	3.82	4.19	0.12
	90-115	62.7	2.5	117.6	13.5	0.26	0.59	4.53	5.92	0.12
Profile- 9	0-20	144.3	1.7	146.4	15.0	0.30	1.02	4.37	12.91	0.20
	20-45	85.3	3.8	132.0	9.1	0.28	0.90	3.32	9.11	0.16
	45-72	62.7	7.5	110.4	3.3	0.45	1.02	3.67	9.62	0.16
	72-110	57.7	2.1	129.6	2.6	0.64	1.04	4.50	10.06	0.14
Profile-10	0-15	143.0	22.2	180.0	27.0	1.42	1.53	8.54	21.42	0.06
	15-30	107.9	8.4	154.8	18.6	1.07	0.87	5.67	8.22	0.06
	30-60	75.3	7.5	169.2	16.8	0.34	1.10	7.14	4.77	0.04
	60-90	50.2	4.6	172.8	16.1	0.91	1.16	6.24	7.18	0.02
	90-120	45.2	6.3	187.2	15.0	0.35	0.85	4.85	5.82	0.02
Profile-11	0-15	48.9	1.3	61.2	12.1	0.27	0.47	2.51	7.41	0.10
	15-70	32.6	3.8	25.2	11.3	0.18	0.23	1.71	4.81	0.08
	70-110	35.1	3.4	165.6	6.6	0.36	0.70	6.29	6.33	0.20

in site four. The highest available nitrogen content was observed in surface horizon and the lowest available nitrogen content was recorded in the last horizon.

4.5.5.2 Available phosphorus

The available phosphorus content of soils varied from low to high in the profile samples. Considering the surface layers, the highest available phosphorus content of 56.3 kg ha⁻¹ was observed in P₁, which was high and lowest available phosphorus content of 1.3 kg ha⁻¹ was observed in P₁₁.

4.5.5.3 Available potassium

The available potassium content of soils varied from low to medium range in nutrient rating and a wide variation could be observed with in the profiles. It ranged from a lowest value of 25.2 kg ha⁻¹ in P₁₁ to a highest value of 398.4 kg ha⁻¹ in P₂.

4.5.5.4 Available sulphur

The available sulphur content of soils varied from low to high in nutrient rating. The maximum content was noticed in surface layer and it decreased with the depth in all the profiles. The available sulphur content varied from 3.29 to 49.69 mg kg⁻¹ in site one, from 0.4 to 44.9 mg kg⁻¹ in site two, from 1.1 to 25.9 mg kg⁻¹ in site three and 2.6 to 30.0 mg kg⁻¹ in site four.

4.5.5.5 Available zinc

The available zinc content of soils varied much among the profiles (Tables 4.20 to 4.23). The zinc content ranged from 0.12 to 2.16 mg kg⁻¹. The highest was found in P₂ and the lowest was found in P₅.

4.5.5.6 Available copper

The available copper content of soils varied with depth in all the profiles. The highest value 2.99 mg kg⁻¹ was found in P₂ and the lowest value 0.24 mg kg⁻¹ was found in P₁₁.

4.5.5.7 Available iron

The available iron content of soil ranged from 1.52 to 18.22 mg kg⁻¹. The highest was observed in P₁ and the lowest observed was in P₂. The available iron content of soil has decreased with the depth of profile and highest value was observed always in surface layer except in the P₃ and P₁₁.

4.5.5.8 Available manganese

The highest available manganese content of soils was observed in the P₁₀ and the lowest value was observed in P₄. The value ranged from 21.42 to 1.44 mg kg⁻¹.

4.5.5.9 Available boron

The available boron content of soils varied much with the profiles. The highest was found (2.99 mg kg⁻¹) in P₁ and the lowest was found (0.24 mg kg⁻¹) in P₁₀.

4.5.5.10 Relationship among selected characters of profile soil samples

The correlation co-efficient among the selected soil characters are presented in Table 4.24. The clay content was highly positively correlated with CEC (0.793**) and exch. Na (0.613**). Similarly the pH was highly positively correlated with ECe (0.712**), ESP (0.856**) and exch. Na (0.794**).

II. Field Experiments:

4.6 Effect of different levels and ratios of nutrients on rice growth, yield, uptake of nutrients and nutrient use efficiency.

The results of the field experiments conducted during *Kharif* 2013 and summer 2014 to study the effect of nutrients (nitrogen, phosphorus and potassium) levels and ratios on growth, yield and nutrient uptake by rice in gypsum amended sodic soil are presented in this chapter.

Table 4.24: Correlation matrix for some selected soil properties of profile in the study sites.

	Sand	Silt	Clay	pH	ECe	OC	CaCO₃	CEC	ESP	Na⁺
Sand	1									
Silt	-0.662**	1								
Clay	-0.931**	0.343*	1							
pH	-0.035	-0.321*	0.201	1						
ECe	0.077	-0.357*	0.077	0.712**	1					
OC	0.057	0.085	-0.112	-0.269	-0.035	1				
CaCO₃	-0.154	0.093	0.148	0.180	0.067	0.449**	1			
CEC	-0.867**	0.601**	0.793**	-0.116	-0.184	0.017	0.217	1		
ESP	0.073	-0.372**	0.090	0.856**	0.756**	-0.162	0.098	-0.322*	1	
Na⁺	-0.479**	-0.025	0.613**	0.794**	0.583**	-0.192	0.354*	0.287*	0.698**	1

- * Significant at 5 per cent level = 0.279
- ** Significant at 1 per cent level = 0.361

4.6.1 Growth parameters, yield attributes, grain and straw yield of rice

The yield (grain and straw), growth parameters (plant height and number of tillers) and yield parameters (number of productive tillers, panicle length, number of grains per panicle and test weight) were higher in all the treatments during 2014 summer compared to 2013 *Kharif* crop (Table 4.25 to 4.28).

4.6.1.1 Plant height (cm)

Plant height varied significantly due to levels and ratios of nutrients during *Kharif* 2013 and summer 2014 (Table 4.25).

Plant height has increased significantly in the treatments receiving NPK during both the years over the control. Taller plants were observed in T₁₂ during 2013 and in T₁₅ during 2014 over the control (T₁₂: 61.1 cm and T₁₅: 73.0 cm, respectively) which were on par with each other in both the years. Pooled analysis of two seasons experimental results revealed that the treatment receiving NPK ratio of 3:1:1 (150:50:50 kg NPK ha⁻¹) produced taller plants (66.6 cm) as compared to other treatments and it was on par with the treatments T₁₆, T₁₇, T₁₈, T₁₄, T₁₀, T₁₂, T₁₃ and T₁₁ (65.7, 65.6, 65.6, 65.5, 65.3, 64.6, 64.5 and 63.9 cm, respectively). Lower plant height of 46.2 cm was recorded in control.

4.6.1.2 Number of tillers hill⁻¹

Effect of nitrogen, phosphorus and potassium levels and ratios had significant effect on number of tillers hill⁻¹ in both the seasons (Table 4.25). Higher number of tillers was observed in T₁₂ receiving during 2013 and in T₁₅ receiving during 2014 over the control (12.6 and 22.4, respectively) which is on par with each other in both the seasons. Pooled analysis revealed that treatment receiving NPK ratio of 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) produced significantly more number of tillers hill⁻¹ (16.9) as compared to control (7.6). However, it was on par with treatments from T₁₇, T₁₄, T₁₆, T₁₂, T₁₈, T₁₃, T₁₀ and T₁₁ (16.7, 16.6, 16.6, 16.5, 16.3, 15.8, 15.3 and 15.3, respectively).

Table 4.25: Effect of NPK levels and ratios on plant height and number of tillers per hill of rice crop in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K ratio	Plant height (cm)			Number of tillers per hill		
	kg ha ⁻¹				2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	53.6	61.7	57.6	10.2	14.7	12.5
T ₂	100	37.5	75	2.7:1:2.0	54.1	62.8	58.5	10.2	15.4	12.8
T ₃	100	50	50	2.0:1:1.0	55.1	63.1	59.1	10.2	17.0	13.6
T ₄	100	50	75	2.0:1:1.5	55.1	65.3	60.2	10.3	16.8	13.5
T ₅	100	62.5	50	1.6:1:0.8	56.0	65.9	60.9	10.5	17.4	14.0
T ₆	100	62.5	75	1.6:1:1.2	59.5	65.8	62.6	10.8	17.6	14.2
T ₇	125	37.5	50	3.3:1:1.3	55.3	66.1	60.7	10.3	18.5	14.4
T ₈	125	37.5	75	3.3:1:2.0	58.8	66.3	62.6	10.8	18.2	14.5
T ₉	125	50	50	2.5:1:1.0	59.1	67.3	63.2	10.4	18.5	14.4
T ₁₀	125	50	75	2.5:1:1.5	60.0	68.9	64.5	10.9	19.8	15.3
T ₁₁	125	62.5	50	2.0:1:0.8	60.2	67.6	63.9	11.2	19.5	15.3
T ₁₂	125	62.5	75	2.0:1:1.2	61.1	69.5	65.3	12.6	20.4	16.5
T ₁₃	150	37.5	50	4.0:1:1.3	59.4	69.9	64.6	10.8	20.8	15.8
T ₁₄	150	37.5	75	4.0:1:2.0	60.1	70.9	65.5	11.0	22.1	16.6
T ₁₅	150	50	50	3.0:1:1.0	60.3	73.0	66.6	11.4	22.4	16.9
T ₁₆	150	50	75	3.0:1:1.5	60.7	70.8	65.7	11.5	21.6	16.6
T ₁₇	150	62.5	50	2.4:1:0.8	60.7	70.5	65.6	12.5	20.8	16.7
T ₁₈	150	62.5	75	2.4:1:1.2	60.5	70.6	65.6	11.5	21.1	16.3
T ₁₉	0	0	0	0:0:0	49.1	43.3	46.2	7.1	8.1	7.6
S. Em±					1.4	1.6	1.1	1.0	0.6	0.7
C. D. at 5%					4.0	4.6	3.0	NS	1.8	1.6

4.6.1.3 Number of productive tillers hill⁻¹

Effect of different levels and ratios of nitrogen, phosphorus and potassium had significant effect on the number of productive tillers per hill⁻¹ during 2013 and 2014 (Table 4.26). Higher number of tillers were observed in NPK ratio of 2:1:1.2 (125:62.5:75) during 2013 and in 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) during 2014 over the control (10.3 and 20.2, respectively). The pooled analysis revealed that treatment receiving NPK ratio of 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) produced more number of productive tillers hill⁻¹ (14.9). However, it was on par with treatments T₁₆, T₁₄, T₁₇, T₁₂, T₁₈, T₁₁ and T₁₀ (14.8, 14.5, 14.4, 14.4, 14.3, 14.3, 13.5 and 13.4, respectively) having different NPK ratios. Lower number of productive tillers hill⁻¹ (6.8) was recorded in control.

4.6.1.4 Panicle length (cm)

Application of different levels and ratios of nitrogen, phosphorus and potassium had significant effect on the panicle length (cm) of rice during both the seasons (Table 4.26). Higher panicle length was observed in T₁₂ i.e. NPK ratio of 2:1:1.2 (125:62.5:75 kg N:P₂O₅:K₂O ha⁻¹) during 2013 and in T₁₅ i.e. 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) during 2014 over the control (19.7 and 26.7 cm, respectively) which were on par with each other. The pooled analysis of 2013 and 2014 results revealed that treatment receiving NPK ratio of 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) produced significantly higher panicle length (22.9 cm) and it was on par with the RDF (T₁₁: 21.3 cm) treatment T₁₂, T₁₆, T₁₇, T₁₈, T₁₃ and T₁₀ (22.1, 22.1, 22.0, 22.0, 21.9, 21.6, 21.3 and 21.1 cm, respectively) and control recorded lowest panicle length (16.0 cm).

4.6.1.5 Number of grains per panicle

Number of grains per panicle increased significantly due to application of different levels and ratios of nitrogen, phosphorus and potassium in both the seasons (2013 and 2014) over control (Table 4.27). The treatment T₁₂ receiving NPK ratio of 2:1:1.2 (125:62.5:75 kg N:P₂O₅:K₂O ha⁻¹) during 2013 and T₁₅ receiving NPK ratio of 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) recorded higher number of grains per panicle (166.6 and 196.1, respectively), however they were on par with each other during both

Table 4.26: Effect of NPK levels and ratios on number of productive tillers per hill and panicle length of rice in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K ratio	No. of productive tillers per hill			Panicle length (cm)		
	kg ha ⁻¹				2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	8.2	12.8	10.5	16.8	21.3	19.1
T ₂	100	37.5	75	2.7:1:2.0	8.3	13.3	10.8	17.9	21.2	19.6
T ₃	100	50	50	2.0:1:1.0	8.4	13.8	11.1	18.4	20.8	19.6
T ₄	100	50	75	2.0:1:1.5	8.5	15.2	11.8	18.4	21.3	19.9
T ₅	100	62.5	50	1.6:1:0.8	8.6	15.5	12.1	18.6	21.3	20.0
T ₆	100	62.5	75	1.6:1:1.2	9.0	15.7	12.4	18.9	22.1	20.5
T ₇	125	37.5	50	3.3:1:1.3	8.5	16.3	12.4	18.5	22.4	20.4
T ₈	125	37.5	75	3.3:1:2.0	8.7	16.6	12.7	18.5	23.1	20.8
T ₉	125	50	50	2.5:1:1.0	8.8	16.4	12.6	18.7	22.4	20.5
T ₁₀	125	50	75	2.5:1:1.5	9.0	17.8	13.4	18.8	23.4	21.1
T ₁₁	125	62.5	50	2.0:1:0.8	9.5	17.6	13.5	19.0	23.6	21.3
T ₁₂	125	62.5	75	2.0:1:1.2	10.3	18.3	14.3	19.7	24.5	22.1
T ₁₃	150	37.5	50	4.0:1:1.3	8.9	18.6	13.7	18.7	24.5	21.6
T ₁₄	150	37.5	75	4.0:1:2.0	9.3	19.8	14.5	18.9	25.1	22.0
T ₁₅	150	50	50	3.0:1:1.0	9.7	20.2	14.9	19.1	26.7	22.9
T ₁₆	150	50	75	3.0:1:1.5	10.1	19.5	14.8	19.3	24.9	22.1
T ₁₇	150	62.5	50	2.4:1:0.8	10.2	18.7	14.4	19.5	24.6	22.0
T ₁₈	150	62.5	75	2.4:1:1.2	9.7	18.9	14.3	19.1	24.7	21.9
T ₁₉	0	0	0	0:0:0	6.6	7.0	6.8	15.5	16.4	16.0
S. Em±					0.8	0.7	0.5	1.0	0.8	0.6
C. D. at 5%					NS	2.1	1.5	NS	2.2	1.8

Table 4.27: Effect of NPK levels and ratios on number of seeds per panicle and test weight of rice in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K ratio	Number of grains per panicle			Test weight (gm)		
	kg ha ⁻¹				2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	147.0	165.3	156.2	25.2	24.4	24.8
T ₂	100	37.5	75	2.7:1:2.0	148.8	167.5	158.2	25.5	24.8	25.2
T ₃	100	50	50	2.0:1:1.0	150.8	170.7	160.8	25.7	24.2	25.0
T ₄	100	50	75	2.0:1:1.5	152.0	168.9	160.5	25.9	25.1	25.5
T ₅	100	62.5	50	1.6:1:0.8	153.4	172.5	163.0	26.0	25.2	25.6
T ₆	100	62.5	75	1.6:1:1.2	158.0	176.4	167.2	26.5	26.2	26.4
T ₇	125	37.5	50	3.3:1:1.3	152.2	177.3	164.8	26.0	25.9	26.0
T ₈	125	37.5	75	3.3:1:2.0	154.0	178.4	166.2	26.1	26.8	26.5
T ₉	125	50	50	2.5:1:1.0	154.0	178.7	166.4	26.2	27.3	26.8
T ₁₀	125	50	75	2.5:1:1.5	158.9	179.8	169.4	26.9	27.7	27.3
T ₁₁	125	62.5	50	2.0:1:0.8	161.1	182.8	172.0	27.4	27.6	27.5
T ₁₂	125	62.5	75	2.0:1:1.2	166.6	187.3	177.0	28.6	28.2	28.4
T ₁₃	150	37.5	50	4.0:1:1.3	156.0	186.4	171.2	26.5	28.0	27.3
T ₁₄	150	37.5	75	4.0:1:2.0	159.1	195.2	177.2	27.2	28.9	28.1
T ₁₅	150	50	50	3.0:1:1.0	163.0	196.1	179.6	27.7	29.1	28.4
T ₁₆	150	50	75	3.0:1:1.5	164.1	192.4	178.3	28.2	28.6	28.4
T ₁₇	150	62.5	50	2.4:1:0.8	165.2	187.3	176.3	28.5	28.3	28.4
T ₁₈	150	62.5	75	2.4:1:1.2	163.2	190.4	176.8	27.8	28.4	28.1
T ₁₉	0	0	0	0:0:0	132.0	145.2	138.6	23.6	23.4	23.5
S. Em±					5.9	8.0	5.0	0.7	0.5	0.4
C. D. at 5%					NS	22.9	14.0	2.0	1.4	1.2

seasons. The pooled analysis data revealed that the treatment receiving NPK ratio of 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) recorded more number of grains panicle⁻¹ (179.6). However, it was on par with the RDF (T₁₁) and other treatments T₁₂, T₁₄, T₁₆, , T₁₈, T₁₇, T₁₃, T₁₀, T₉ and T₈ (178.3, 177.2, 177.0, 176.8, 176.3, 172.0, 171.2, 169.4, 166.4 and 166.2, respectively). Lower number of grains panicle⁻¹ was observed in control (138.6).

4.6.1.6 Test weight (g)

The test weight differed significantly due to application of nitrogen, phosphorus and potassium at all levels and ratios tried over the control during 2013 and 2014 (Table 4.27). Among different treatments, the treatments receiving NPK ratio of 2:1:1.4 (T₁₂) and 3:1:1 (T₁₅) recorded higher test weight in 2013 and 2014 (28.6 and 29.1 g, respectively). The pooled analysis of 2013 and 2014 results revealed that the treatment receiving NPK ratio of 2:1:1.4 (T₁₂), 3:1:1 (T₁₅), 3:1:1.5 (T₁₆) and 2.4:1:0.8 (T₁₇) recorded significantly higher test weight (28.4 g), however it was on par with T₁₄, T₁₈, T₁₁, T₁₀ and T₁₃ (28.1, 28.1, 27.5, 27.3 and 27.3 g, respectively). Lowest test weight of 23.5 g was recorded in control.

4.6.1.7 Grain yield (t ha⁻¹)

Significant increase in grain yield was noticed due to application of NPK at all levels/ratios compared to control (Table 4.28). Similarly, the grain yield of rice differed significantly due to application of different levels and ratios of nitrogen, phosphorus and potassium during 2013 and 2014. However, grain and straw yield was higher in the summer 2014 crop compared to *Kharif* 2013 crop. During 2013 *Kharif* season the grain yield in control was 2.99 t ha⁻¹ which increased significantly to 4.62 t ha⁻¹ due to application of NPK in the ratio of 2:1:1.2 (125:62.5:75 kg N:P₂O₅:K₂O ha⁻¹) and it was statistically at par with the grain yield obtained in T₁₅ treatment (4.54 t ha⁻¹). While during 2014 the grain yield in control was 2.65 t ha⁻¹, which increased significantly to 6.21 t ha⁻¹ due to application of NPK in the ratio of 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) and it was on par with the T₁₂ treatment (6.04 t ha⁻¹).

The pooled analysis of two seasons results (2013 and 2014) revealed that the treatments which received NPK ratio of 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) and

Table 4.28: Effect of NPK levels and ratios on grain and straw yield of rice in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K ratio	Grain yield (t ha ⁻¹)			Straw yield (t ha ⁻¹)		
	kg ha ⁻¹				2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	3.95	4.82	4.38	5.10	5.76	5.43
T ₂	100	37.5	75	2.7:1:2.0	4.04	5.05	4.55	5.15	6.03	5.59
T ₃	100	50	50	2.0:1:1.0	4.15	5.26	4.71	5.18	6.28	5.73
T ₄	100	50	75	2.0:1:1.5	4.18	5.34	4.76	5.22	6.38	5.80
T ₅	100	62.5	50	1.6:1:0.8	4.24	5.49	4.87	5.26	6.57	5.91
T ₆	100	62.5	75	1.6:1:1.2	4.35	5.57	4.96	5.61	6.65	6.13
T ₇	125	37.5	50	3.3:1:1.3	4.23	5.70	4.97	5.24	6.81	6.03
T ₈	125	37.5	75	3.3:1:2.0	4.26	5.89	5.08	5.28	7.03	6.16
T ₉	125	50	50	2.5:1:1.0	4.32	5.91	5.11	5.49	7.06	6.28
T ₁₀	125	50	75	2.5:1:1.5	4.38	5.99	5.19	5.62	7.15	6.39
T ₁₁	125	62.5	50	2.0:1:0.8	4.46	5.92	5.19	5.77	7.07	6.42
T ₁₂	125	62.5	75	2.0:1:1.2	4.62	6.04	5.33	5.99	7.21	6.60
T ₁₃	150	37.5	50	4.0:1:1.3	4.35	6.04	5.19	5.53	7.48	6.51
T ₁₄	150	37.5	75	4.0:1:2.0	4.44	6.14	5.29	5.65	7.60	6.62
T ₁₅	150	50	50	3.0:1:1.0	4.54	6.21	5.37	5.83	7.76	6.79
T ₁₆	150	50	75	3.0:1:1.5	4.61	6.14	5.37	5.86	7.71	6.79
T ₁₇	150	62.5	50	2.4:1:0.8	4.57	6.04	5.30	5.96	7.58	6.77
T ₁₈	150	62.5	75	2.4:1:1.2	4.57	6.07	5.32	5.84	7.63	6.73
T ₁₉	0	0	0	0:0:0	2.99	2.65	2.82	4.04	3.33	3.69
S. Em±					0.10	0.09	0.07	0.14	0.14	0.10
C. D. at 5%					0.29	0.27	0.19	0.41	0.39	0.28

3:1:1.5 (150:50:75 kg N:P₂O₅:K₂O ha⁻¹) recorded significantly highest grain yield (5.37 t ha⁻¹) as compared to control (2.82 t ha⁻¹) and rest of the treatments except T₁₂, T₁₈, T₁₇, T₁₄, T₁₀, T₁₁ (RDF) and T₁₃ (5.33, 5.32, 5.30, 5.29, 5.19, 5.19 and 5.19 t ha⁻¹, respectively).

4.6.1.8 Straw yield (t ha⁻¹)

The effect of different levels and ratios of nitrogen, phosphorus and potassium was significant on straw yield of rice over the control (Table 4.28). Among treatments, the treatment receiving NPK ratio of 2:1:1.2 (125:62.5:75 kg N:P₂O₅:K₂O ha⁻¹) and 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) recorded highest straw yield (5.99 and 7.76 t ha⁻¹, respectively) as compared to the rest of the treatments and control. Pooled analysis revealed that the treatment receiving NPK ratio of 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) and 3:1:1.5 (150:50:75 kg N:P₂O₅:K₂O ha⁻¹) recorded significantly higher straw yield (6.79 t ha⁻¹) as compared to rest of the treatments. However, they were on par with the treatments T₁₇, T₁₈, T₁₄, T₁₂ and T₁₃ (6.77, 6.73, 6.62, 6.60 and 6.51 t ha⁻¹, respectively), and control recorded the lowest straw yield (3.69 t ha⁻¹).

4.7 Nutrient concentration in grain

4.7.1 Nitrogen, phosphorus and potassium

The influence of different levels and ratios of NPK on NPK content in grains was not significant at harvest during 2013 and 2014 (Table 4.29). The concentration of nitrogen and potassium was higher in rice grain grown during summer 2014 compared to *Kharif* 2013 where as phosphorus showed reverse trend.

During both the years (2013 and 2014) nitrogen, phosphorus and potassium concentration in rice grain was significantly higher in T₁₅ treatment that received NPK ratio of 3:1:1 (1.26, 0.57, 0.33 % and 1.59, 0.37, 0.43 %, respectively) compared to all other treatments which received NPK at different levels and ratios.

The pooled analysis of two years results (2013 and 2014) revealed that the concentration of N, P and K in rice grain was higher in the treatment T₁₅ which received NPK @ 150:50:50 kg ha⁻¹ (1.42, 0.47 and 0.38 %, respectively). Lower concentration of

Table 4.29: Effect of NPK levels and ratios on N, P and K concentration (%) of rice grain in gypsum amended sodic soil during Kharif 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K ratio	N			P			K		
	kg ha ⁻¹				2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	0.98	1.28	1.13	0.49	0.28	0.38	0.32	0.37	0.35
T ₂	100	37.5	75	2.7:1:2.0	1.02	1.29	1.16	0.47	0.26	0.36	0.32	0.36	0.34
T ₃	100	50	50	2.0:1:1.0	1.02	1.35	1.19	0.50	0.29	0.39	0.31	0.36	0.34
T ₄	100	50	75	2.0:1:1.5	1.04	1.35	1.20	0.49	0.25	0.37	0.34	0.37	0.36
T ₅	100	62.5	50	1.6:1:0.8	1.04	1.37	1.21	0.43	0.26	0.35	0.32	0.39	0.35
T ₆	100	62.5	75	1.6:1:1.2	1.06	1.39	1.23	0.55	0.28	0.42	0.33	0.34	0.33
T ₇	125	37.5	50	3.3:1:1.3	1.09	1.40	1.25	0.53	0.31	0.42	0.33	0.35	0.34
T ₈	125	37.5	75	3.3:1:2.0	1.08	1.42	1.25	0.51	0.29	0.40	0.31	0.39	0.35
T ₉	125	50	50	2.5:1:1.0	1.09	1.44	1.27	0.55	0.32	0.43	0.32	0.34	0.33
T ₁₀	125	50	75	2.5:1:1.5	1.12	1.40	1.26	0.49	0.32	0.40	0.31	0.36	0.34
T ₁₁	125	62.5	50	2.0:1:0.8	1.13	1.48	1.31	0.52	0.29	0.41	0.30	0.33	0.31
T ₁₂	125	62.5	75	2.0:1:1.2	1.12	1.48	1.30	0.54	0.30	0.42	0.39	0.34	0.36
T ₁₃	150	37.5	50	4.0:1:1.3	1.13	1.50	1.32	0.52	0.30	0.41	0.31	0.35	0.33
T ₁₄	150	37.5	75	4.0:1:2.0	1.15	1.52	1.34	0.50	0.33	0.41	0.30	0.39	0.34
T ₁₅	150	50	50	3.0:1:1.0	1.26	1.59	1.42	0.57	0.37	0.47	0.33	0.43	0.38
T ₁₆	150	50	75	3.0:1:1.5	1.22	1.57	1.40	0.50	0.32	0.41	0.33	0.35	0.34
T ₁₇	150	62.5	50	2.4:1:0.8	1.16	1.50	1.33	0.59	0.33	0.46	0.38	0.36	0.37
T ₁₈	150	62.5	75	2.4:1:1.2	1.20	1.56	1.38	0.54	0.32	0.43	0.35	0.33	0.34
T ₁₉	0	0	0	0:0:0	0.98	1.29	1.14	0.51	0.23	0.37	0.31	0.32	0.32
S. Em±					0.07	0.08	0.05	0.03	0.02	0.02	0.02	0.03	0.02
C. D. at 5%					NS	NS	0.15	NS	NS	0.05	NS	NS	NS

N, P and K was recorded in the treatment T₁₉ (control) which received gypsum and FYM (1.14, 0.37 and 0.32 %, respectively).

4.7.2 Calcium, magnesium and sulphur

The effect of varied levels and ratios of NPK on the calcium, magnesium and sulphur content in rice grain was non-significant (Table 4.30). However higher concentration of Ca, Mg and S (0.16, 0.11 and 0.19%, respectively) was recorded in the treatment receiving NPK ratio of 3:1:1 (150:50:50 kg ha⁻¹).

4.7.3 Sodium and micronutrients

The concentration of sodium, iron, manganese and boron were higher in rice crop grown during *Kharif* 2013 as compared to the crop grown during summer 2014 (Table 4.31 and 4.32).

The pooled analysis of two years (2013 and 2014) data revealed that the concentrations of Na, Fe, Zn, Cu, Mn and B in rice grain did not vary significantly. The concentration of Na varied from 0.02 to 0.04%. The concentration of Zn, Cu, Fe, Mn and B were varied from 17.01 to 22.90, 6.19 to 8.12, 160.29 to 200.18, 45.26 to 52.73 and 13.63 to 16.63 mg kg⁻¹, respectively in different treatments receiving NPK without definite trend in content during both the seasons.

4.8 Nutrient concentration in straw

4.8.1 Nitrogen, phosphorus and potassium

The concentration of nitrogen, phosphorus and potassium in rice straw was non-significant due to NPK application at harvest (Table 4.33). The concentration of nitrogen, phosphorus and potassium was higher in rice straw during summer 2014 over *Kharif* 2013.

The pooled analysis over two years (2013 and 2014) results revealed that the concentration of N, P and K in rice straw was higher in the treatment T₁₅ receiving NPK @ 150:50:50 kg ha⁻¹ i.e. 3:1:1 ratio (0.76, 0.17 and 0.95%, respectively). Lower

Table 4.30: Effect of NPK levels and ratios on Ca, Mg and S concentration (%) of rice grain in gypsum amended sodic soil during *Kharif* 2013 and summer 2014

[illegible]

Table 4.31: Effect of NPK levels and ratios on Na (%), Zn and Cu concentration (mg kg⁻¹) of rice grain in gypsum amended sodic soil during *Kharif* 2013 and summer 2014

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K ratio	Na			Zn			Cu		
	kg ha ⁻¹				2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	0.04	0.01	0.03	19.77	17.13	18.45	6.75	6.02	6.38
T ₂	100	37.5	75	2.7:1:2.0	0.03	0.01	0.02	18.33	16.45	17.39	6.35	6.03	6.19
T ₃	100	50	50	2.0:1:1.0	0.04	0.02	0.03	17.20	16.83	17.01	7.23	6.64	6.94
T ₄	100	50	75	2.0:1:1.5	0.03	0.01	0.02	18.05	18.86	18.45	7.08	6.51	6.80
T ₅	100	62.5	50	1.6:1:0.8	0.03	0.02	0.02	16.72	18.35	17.53	6.60	6.62	6.61
T ₆	100	62.5	75	1.6:1:1.2	0.04	0.02	0.03	17.97	19.65	18.81	6.72	7.23	6.97
T ₇	125	37.5	50	3.3:1:1.3	0.04	0.02	0.03	21.48	21.48	21.48	7.18	8.08	7.63
T ₈	125	37.5	75	3.3:1:2.0	0.04	0.01	0.03	19.43	20.33	19.88	6.93	6.53	6.73
T ₉	125	50	50	2.5:1:1.0	0.04	0.01	0.03	18.53	19.21	18.87	6.00	6.47	6.23
T ₁₀	125	50	75	2.5:1:1.5	0.03	0.01	0.02	17.20	19.84	18.52	6.57	7.18	6.87
T ₁₁	125	62.5	50	2.0:1:0.8	0.04	0.02	0.03	19.43	20.35	19.89	5.97	6.99	6.48
T ₁₂	125	62.5	75	2.0:1:1.2	0.03	0.02	0.02	20.73	20.42	20.58	7.28	7.50	7.39
T ₁₃	150	37.5	50	4.0:1:1.3	0.04	0.02	0.03	15.45	18.36	16.90	7.67	8.28	7.98
T ₁₄	150	37.5	75	4.0:1:2.0	0.04	0.02	0.03	16.18	20.74	18.46	7.37	8.88	8.12
T ₁₅	150	50	50	3.0:1:1.0	0.03	0.03	0.03	18.57	22.08	20.33	7.08	7.48	7.28
T ₁₆	150	50	75	3.0:1:1.5	0.04	0.02	0.03	24.12	20.48	22.30	7.70	7.70	7.70
T ₁₇	150	62.5	50	2.4:1:0.8	0.04	0.02	0.03	23.00	22.79	22.90	7.57	8.27	7.92
T ₁₈	150	62.5	75	2.4:1:1.2	0.04	0.02	0.03	16.43	21.98	19.21	7.82	7.48	7.65
T ₁₉	0	0	0	0:0:0	0.06	0.03	0.04	14.23	20.35	17.29	7.62	6.63	7.13
S. Em±					0.00	0.00	0.00	1.67	2.19	1.38	0.74	0.62	0.48
C. D. at 5%					0.01	0.01	0.01	4.79	NS	NS	NS	NS	NS

Table 4.33: Effect of NPK levels and ratios on N, P and K concentration (%) of rice straw in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K ratio	N			P			K		
	kg ha ⁻¹				2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	0.62	0.60	0.61	0.20	0.10	0.15	0.99	0.75	0.87
T ₂	100	37.5	75	2.7:1:2.0	0.63	0.63	0.63	0.20	0.15	0.17	1.07	0.80	0.94
T ₃	100	50	50	2.0:1:1.0	0.65	0.64	0.64	0.21	0.11	0.16	1.04	0.78	0.91
T ₄	100	50	75	2.0:1:1.5	0.65	0.65	0.65	0.22	0.12	0.17	1.03	0.79	0.91
T ₅	100	62.5	50	1.6:1:0.8	0.66	0.59	0.62	0.18	0.09	0.13	1.11	0.77	0.94
T ₆	100	62.5	75	1.6:1:1.2	0.66	0.63	0.64	0.24	0.10	0.17	1.03	0.82	0.93
T ₇	125	37.5	50	3.3:1:1.3	0.67	0.65	0.66	0.18	0.11	0.15	1.03	0.73	0.88
T ₈	125	37.5	75	3.3:1:2.0	0.66	0.64	0.65	0.19	0.11	0.15	1.02	0.76	0.89
T ₉	125	50	50	2.5:1:1.0	0.67	0.65	0.66	0.22	0.13	0.18	1.12	0.78	0.95
T ₁₀	125	50	75	2.5:1:1.5	0.70	0.66	0.68	0.18	0.14	0.16	1.12	0.73	0.92
T ₁₁	125	62.5	50	2.0:1:0.8	0.72	0.66	0.69	0.19	0.10	0.14	1.08	0.76	0.92
T ₁₂	125	62.5	75	2.0:1:1.2	0.71	0.68	0.70	0.24	0.10	0.17	1.13	0.79	0.96
T ₁₃	150	37.5	50	4.0:1:1.3	0.73	0.70	0.71	0.21	0.10	0.15	1.02	0.82	0.92
T ₁₄	150	37.5	75	4.0:1:2.0	0.74	0.70	0.72	0.22	0.10	0.16	1.09	0.76	0.92
T ₁₅	150	50	50	3.0:1:1.0	0.79	0.73	0.76	0.20	0.14	0.17	1.05	0.85	0.95
T ₁₆	150	50	75	3.0:1:1.5	0.78	0.72	0.75	0.21	0.12	0.16	1.12	0.78	0.95
T ₁₇	150	62.5	50	2.4:1:0.8	0.74	0.71	0.72	0.20	0.12	0.16	1.10	0.80	0.95
T ₁₈	150	62.5	75	2.4:1:1.2	0.75	0.72	0.73	0.19	0.12	0.16	1.09	0.83	0.96
T ₁₉	0	0	0	0:0:0	0.59	0.54	0.57	0.20	0.12	0.16	0.73	0.62	0.67
S. Em±					0.05	0.05	0.04	0.02	0.01	0.01	0.06	0.04	0.04
C. D. at 5%					NS	NS	0.10	NS	0.02	NS	0.17	NS	0.10

concentration of N, P and K was recorded in the treatment T₁₉ (0.57, 0.16 and 0.67%, respectively).

4.8.2 Calcium, magnesium and sulphur

The data presented in Table 4.34 revealed that the concentration of calcium, magnesium and sulphur in rice straw did not differ significantly due to NPK application in different ratios. The concentration of calcium and sulphur was higher in rice straw during *Kharif* 2013 than summer 2014.

Pooled analysis indicated that the Ca, Mg and S concentration in rice straw varied from 0.29 to 0.38, 0.12 to 0.18 and 0.13 to 0.21%, respectively in the treatment T₁₅ receiving NPK @ 150:50:50 kg ha⁻¹ (3:1:1 ratio).

4.8.3 Sodium and micronutrients

The concentration of sodium and micronutrients in rice straw as influenced by levels and ratios of NPK at harvest is presented in Tables 4.35 and 4.36. The concentration of Zn, Cu and B was higher in rice straw grown during summer 2014 over *Kharif* 2013.

Higher concentration of sodium was observed during *Kharif* 2013 than summer 2014 in all the treatments receiving NPK. The results of pooled analysis showed that the sodium content varied from 0.30 to 0.46% and higher sodium was recorded in control.

The results of pooled analysis of two years (2013 and 2014) data revealed that variation in the concentrations of Zn, Cu, Fe, Mn and B in rice straw due to treatments was non-significant. The concentrations of Fe, Zn, Cu, Mn and B were in the range of 17.38 to 21.47, 3.56 to 4.54, 139.48 to 186.04, 169.38 to 220.63 and 13.08 to 18.83 mg kg⁻¹, respectively.

Table 4.35: Effect of NPK levels and ratios on Na (%), Zn and Cu concentration (mg kg⁻¹) of rice straw in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K	Na			Zn			Cu		
	kg ha ⁻¹			ratio	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	0.40	0.32	0.36	14.83	19.92	17.38	3.50	3.88	3.69
T ₂	100	37.5	75	2.7:1:2.0	0.39	0.26	0.32	16.72	22.38	19.55	3.92	3.87	3.89
T ₃	100	50	50	2.0:1:1.0	0.49	0.25	0.37	16.25	21.73	18.99	3.25	3.56	3.40
T ₄	100	50	75	2.0:1:1.5	0.43	0.28	0.36	16.70	19.94	18.32	3.82	4.90	4.36
T ₅	100	62.5	50	1.6:1:0.8	0.38	0.22	0.30	14.98	19.85	17.42	3.30	4.69	4.00
T ₆	100	62.5	75	1.6:1:1.2	0.41	0.49	0.45	16.72	20.41	18.56	3.10	4.60	3.85
T ₇	125	37.5	50	3.3:1:1.3	0.40	0.24	0.32	14.50	22.36	18.43	3.18	4.48	3.83
T ₈	125	37.5	75	3.3:1:2.0	0.46	0.46	0.46	16.85	20.48	18.67	3.73	4.95	4.34
T ₉	125	50	50	2.5:1:1.0	0.38	0.37	0.37	14.88	20.92	17.90	3.83	4.63	4.23
T ₁₀	125	50	75	2.5:1:1.5	0.38	0.35	0.36	15.20	20.92	18.06	3.88	4.75	4.32
T ₁₁	125	62.5	50	2.0:1:0.8	0.37	0.33	0.35	15.25	22.92	19.08	3.52	4.30	3.91
T ₁₂	125	62.5	75	2.0:1:1.2	0.40	0.34	0.37	14.22	22.83	18.52	3.63	4.03	3.83
T ₁₃	150	37.5	50	4.0:1:1.3	0.45	0.31	0.38	14.32	23.95	19.13	3.57	4.93	4.25
T ₁₄	150	37.5	75	4.0:1:2.0	0.36	0.35	0.35	16.07	24.64	20.35	3.73	4.68	4.20
T ₁₅	150	50	50	3.0:1:1.0	0.45	0.35	0.40	16.07	24.24	20.15	4.67	4.02	4.34
T ₁₆	150	50	75	3.0:1:1.5	0.46	0.32	0.39	17.15	25.43	21.29	4.18	4.39	4.29
T ₁₇	150	62.5	50	2.4:1:0.8	0.40	0.41	0.41	18.28	24.66	21.47	4.20	4.68	4.44
T ₁₈	150	62.5	75	2.4:1:1.2	0.40	0.28	0.34	16.03	25.87	20.95	4.23	4.85	4.54
T ₁₉	0	0	0	0:0:0	0.65	0.27	0.46	14.72	25.07	19.89	3.62	3.50	3.56
S. Em±					0.04	0.06	0.04	1.30	1.87	1.14	0.37	0.54	0.33
C. D. at 5%					0.13	NS	NS	NS	NS	NS	NS	NS	NS

4.9 Total nutrient uptake by rice crop (grain + straw)

4.9.1 Nitrogen, phosphorus and potassium

The total nitrogen and potassium uptake by rice crop was higher during summer 2014 over *Kharif* 2013, where as the phosphorus uptake was higher in *Kharif* 2013 over summer 2014 (Table 4.37). During both 2013 and 2014 significantly higher nitrogen, phosphorus and potassium uptake by rice was recorded in the treatments receiving NPK at different levels and ratios compared to control.

Significantly higher nitrogen uptake by rice crop was recorded in the treatment T₁₅ receiving NPK fertilizer ratio of 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) during 2013 and 2014 (103.4 and 155.6 kg ha⁻¹, respectively) over control and all other treatments receiving different levels of NPK. The pooled analysis indicated that significantly higher nitrogen uptake by rice (129.5 kg ha⁻¹) was noticed in the treatment T₁₅ receiving NPK ratio of 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹). However, it was on par with the treatment T₁₆, T₁₈, T₁₇ and T₁₄ (126.7, 124.0, 120.8 and 119.8 kg ha⁻¹, respectively). However, significantly lower nitrogen uptake (52.8 kg ha⁻¹) by rice was noticed in treatment T₁₉ (control).

The phosphorus uptake by rice crop differed significantly due to application of NPK in different ratio during 2013 and 2014. The higher P uptake of 39.2 and 33.9 kg ha⁻¹ was recorded in T₁₂ and T₁₅ in 2013 and 2014, respectively. The pooled analysis of data of two years results indicated that significantly higher P uptake by rice crop (35.6 kg ha⁻¹) was noticed in the treatment T₁₅ receiving NPK ratio of 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹). However, it was on par with the treatment T₁₇ (33.8 kg ha⁻¹) receiving NPK ratio of 2.4:1:0.8 (150:62.5:50 kg N:P₂O₅:K₂O ha⁻¹). Lower phosphorus uptake (16.8 kg ha⁻¹) by rice was noticed in treatment T₁₉ (control).

The potassium uptake by rice crop differed significantly over control due to application of NPK at different levels and ratios. The higher K uptake of 85.5 kg ha⁻¹ was recorded in treatment T₁₂ receiving 125:62.5:75 kg NPK ha⁻¹ during 2013 and 93.0 kg ha⁻¹ in T₁₅ receiving 150:50:50 75 kg NPK ha⁻¹ during 2014 respectively. The pooled analysis indicated that significantly higher potassium uptake by rice crop (84.3 kg ha⁻¹)

Table 4.37: Effect of NPK levels and ratios on N, P and K uptake (kg ha⁻¹) by rice crop in gypsum amended sodic soil during Kharif 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K ratio	N			P			K		
	kg ha ⁻¹				2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	70.5	96.4	83.4	29.4	19.2	24.3	62.7	61.5	62.1
T ₂	100	37.5	75	2.7:1:2.0	73.5	103.0	88.3	29.1	21.8	25.5	68.4	66.3	67.3
T ₃	100	50	50	2.0:1:1.0	76.0	111.1	93.6	31.4	22.0	26.7	66.7	68.0	67.4
T ₄	100	50	75	2.0:1:1.5	77.5	113.3	95.4	32.2	21.2	26.7	67.4	70.2	68.8
T ₅	100	62.5	50	1.6:1:0.8	78.8	113.6	96.2	27.5	20.5	24.0	71.7	72.4	72.1
T ₆	100	62.5	75	1.6:1:1.2	83.0	119.6	101.3	37.5	22.4	29.9	72.1	73.6	72.8
T ₇	125	37.5	50	3.3:1:1.3	81.5	123.7	102.6	32.2	25.3	28.7	67.9	70.0	69.0
T ₈	125	37.5	75	3.3:1:2.0	81.0	128.7	104.9	31.5	24.9	28.2	67.3	76.3	71.8
T ₉	125	50	50	2.5:1:1.0	84.0	131.2	107.6	35.9	27.9	31.9	75.1	75.5	75.3
T ₁₀	125	50	75	2.5:1:1.5	88.7	130.9	109.8	31.8	28.8	30.3	76.6	73.9	75.3
T ₁₁	125	62.5	50	2.0:1:0.8	91.9	134.2	113.0	34.0	24.1	29.1	75.3	73.4	74.3
T ₁₂	125	62.5	75	2.0:1:1.2	94.4	138.5	116.4	39.2	25.6	32.4	85.5	77.6	81.6
T ₁₃	150	37.5	50	4.0:1:1.3	89.3	142.6	116.0	34.4	25.6	30.0	69.8	82.9	76.4
T ₁₄	150	37.5	75	4.0:1:2.0	92.7	146.9	119.8	34.8	27.4	31.1	74.5	81.4	78.0
T ₁₅	150	50	50	3.0:1:1.0	103.4	155.6	129.5	37.3	33.9	35.6	75.6	93.0	84.3
T ₁₆	150	50	75	3.0:1:1.5	101.8	151.5	126.7	35.4	28.7	32.0	81.1	81.8	81.5
T ₁₇	150	62.5	50	2.4:1:0.8	97.0	144.6	120.8	38.9	28.6	33.8	83.1	82.9	83.0
T ₁₈	150	62.5	75	2.4:1:1.2	98.8	149.1	124.0	35.7	28.7	32.2	79.5	83.1	81.3
T ₁₉	0	0	0	0:0:0	53.4	52.2	52.8	23.4	10.2	16.8	39.0	29.2	34.1
S. Em±					4.0	6.5	3.8	1.8	1.5	1.2	2.7	3.2	2.1
C. D. at 5%					11.4	18.8	10.8	5.1	4.3	3.3	7.9	9.2	5.9

was noticed in the treatment T₁₅ receiving NPK ratio of 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) followed by T₁₇ (83.0 kg ha⁻¹), T₁₂ (81.6 kg ha⁻¹), T₁₆ (81.5 kg ha⁻¹) and T₁₈ (81.3 kg ha⁻¹). However, significantly lower potassium uptake (34.1 kg ha⁻¹) by rice crop was noticed in treatment T₁₉ (control).

4.9.2 Calcium, magnesium, sulphur and sodium

The results revealed that NPK application at different ratios and levels recorded significantly higher uptake of Ca, Mg and S and Na compared to control during 2013 and 2014 (Table 4.38 and 4.39). Significantly higher calcium uptake by rice (32.9 and 35.6 kg ha⁻¹) was noticed in the treatment T₁₂ and T₁₅ receiving NPK fertilizer ratio of 2:1:1.2 (125:62.5:75 kg N:P₂O₅:K₂O ha⁻¹) and 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) during 2013 and 2014, respectively. The pooled analysis indicated that significantly higher calcium uptake by rice (32.6 kg ha⁻¹) was noticed in the treatment T₁₂ receiving NPK ratio of 2:1:1.2 (125:62.5:75 kg N:P₂O₅:K₂O ha⁻¹) and was on par with treatment T₁₆ (31.8 kg ha⁻¹). However, significantly lower calcium uptake (15.4 kg ha⁻¹) by rice was noticed in treatment T₁₉ (control).

The magnesium uptake was higher in rice crop grown during summer 2014 as compared to crop grown during *Kharif* 2013. Significantly higher uptake of magnesium was observed in treatment T₁₂ and T₁₅ (16.0 and 24.9 kg ha⁻¹, respectively) during both the years. The pooled analysis (2013 and 2014) indicated that significantly higher magnesium uptake by rice (17.5 kg ha⁻¹) was noticed in the treatment T₁₅ receiving NPK ratio of 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹). However, it was on par with the treatment T₁₂, T₁₆, T₁₈, T₁₄, T₁₇, T₁₀, T₁₃, T₁₁, T₉ and T₇ (17.0, 16.5, 16.4, 16.2, 16.2, 15.4, 14.7, 14.6, 14.1 and 13.9 kg ha⁻¹, respectively). Lower magnesium uptake (6.9 kg ha⁻¹) by rice was noticed in treatment T₁₉ (control).

The total uptake of sulphur was higher in rice crop grown during *Kharif* 2013 as compared to crop grown during summer 2014. Higher uptake of sulphur (28.4 and 21.2 kg ha⁻¹, respectively) was observed in treatment T₁₇ and T₁₅ during 2013 and 2014, respectively. The pooled analysis indicated that significantly higher sulphur uptake by rice crop (23.4 kg ha⁻¹) was noticed in the treatment T₁₇ receiving NPK ratio of 2.4:1:0.8

Table 4.38: Effect of NPK levels and ratios on Ca, Mg and S uptake (kg ha⁻¹) by rice crop in gypsum amended sodic soil during Kharif 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K ratio	Ca			Mg			S		
	kg ha ⁻¹				2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	20.7	22.2	21.4	10.8	14.4	12.6	18.2	11.3	14.8
T ₂	100	37.5	75	2.7:1:2.0	21.1	25.4	23.2	11.0	15.2	13.1	18.2	11.5	14.8
T ₃	100	50	50	2.0:1:1.0	23.0	24.1	23.5	11.7	15.0	13.4	20.8	11.6	16.2
T ₄	100	50	75	2.0:1:1.5	24.9	23.2	24.1	10.8	13.8	12.3	18.9	12.9	15.9
T ₅	100	62.5	50	1.6:1:0.8	25.5	24.5	25.0	8.8	16.2	12.5	19.7	12.2	15.9
T ₆	100	62.5	75	1.6:1:1.2	27.6	29.4	28.5	9.6	14.4	12.0	19.2	13.3	16.2
T ₇	125	37.5	50	3.3:1:1.3	23.8	28.4	26.1	10.6	17.1	13.9	18.5	12.7	15.6
T ₈	125	37.5	75	3.3:1:2.0	26.4	25.4	25.9	9.8	14.3	12.0	18.9	12.8	15.8
T ₉	125	50	50	2.5:1:1.0	26.2	26.7	26.5	10.2	18.1	14.1	19.4	14.6	17.0
T ₁₀	125	50	75	2.5:1:1.5	27.1	27.0	27.1	10.8	20.0	15.4	21.1	14.4	17.7
T ₁₁	125	62.5	50	2.0:1:0.8	25.3	28.5	26.9	10.8	18.4	14.6	19.4	14.7	17.1
T ₁₂	125	62.5	75	2.0:1:1.2	32.9	32.3	32.6	16.0	18.0	17.0	27.8	16.6	22.2
T ₁₃	150	37.5	50	4.0:1:1.3	26.7	28.0	27.3	11.2	18.3	14.7	21.1	15.2	18.1
T ₁₄	150	37.5	75	4.0:1:2.0	28.3	28.8	28.5	10.3	22.2	16.2	22.6	18.7	20.6
T ₁₅	150	50	50	3.0:1:1.0	27.1	35.6	31.3	10.0	24.9	17.5	22.8	21.2	22.0
T ₁₆	150	50	75	3.0:1:1.5	29.8	33.8	31.8	11.5	21.4	16.5	26.2	15.4	20.8
T ₁₇	150	62.5	50	2.4:1:0.8	32.6	29.6	31.1	11.8	20.5	16.2	28.4	18.5	23.4
T ₁₈	150	62.5	75	2.4:1:1.2	29.4	29.8	29.6	12.7	20.0	16.4	23.5	15.7	19.6
T ₁₉	0	0	0	0:0:0	18.6	12.2	15.4	5.5	8.3	6.9	11.5	6.3	8.9
S. Em±					1.8	1.7	0.4	1.3	2.19	1.3	1.8	1.5	1.2
C. D. at 5%					5.2	4.7	1.1	3.8	6.28	3.6	5.1	4.3	3.3

Table 4.39: Effect of NPK levels and ratios on sodium (kg ha⁻¹), Zn and Cu uptake (g ha⁻¹) by rice crop in gypsum amended sodic soil during *Kharif* 2013 and summer 2014

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K	Na (kg ha ⁻¹)			Zn (g ha ⁻¹)			Cu (g ha ⁻¹)		
	kg ha ⁻¹			ratio	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	18.6	19.3	19.0	153.8	197.8	175.8	44.5	51.2	47.9
T ₂	100	37.5	75	2.7:1:2.0	21.2	16.2	18.7	159.8	218.9	189.4	46.1	53.8	49.9
T ₃	100	50	50	2.0:1:1.0	26.8	16.3	21.5	155.5	225.4	190.5	46.8	57.1	51.9
T ₄	100	50	75	2.0:1:1.5	24.0	18.9	21.5	162.9	228.6	195.8	49.0	66.3	57.7
T ₅	100	62.5	50	1.6:1:0.8	21.3	15.4	18.3	149.7	230.1	189.9	45.4	67.5	56.4
T ₆	100	62.5	75	1.6:1:1.2	24.3	27.0	25.6	172.4	244.4	208.4	46.7	71.0	58.8
T ₇	125	37.5	50	3.3:1:1.3	22.2	17.4	19.8	165.8	274.4	220.1	47.0	76.9	62.0
T ₈	125	37.5	75	3.3:1:2.0	26.1	33.1	29.6	172.1	263.9	218.0	49.4	73.2	61.3
T ₉	125	50	50	2.5:1:1.0	22.0	26.8	24.4	162.0	260.5	211.3	46.9	70.7	58.8
T ₁₀	125	50	75	2.5:1:1.5	22.6	25.7	24.1	160.9	268.2	214.6	50.5	76.7	63.6
T ₁₁	125	62.5	50	2.0:1:0.8	22.9	24.4	23.6	175.1	282.5	228.8	46.9	71.8	59.3
T ₁₂	125	62.5	75	2.0:1:1.2	25.6	25.2	25.4	181.0	287.9	234.4	55.4	74.3	64.8
T ₁₃	150	37.5	50	4.0:1:1.3	26.5	24.1	25.3	146.5	289.9	218.2	52.9	86.7	69.8
T ₁₄	150	37.5	75	4.0:1:2.0	22.1	27.4	24.7	162.6	314.6	238.6	53.8	90.0	71.9
T ₁₅	150	50	50	3.0:1:1.0	28.1	28.7	28.4	178.0	324.5	251.3	59.3	77.6	68.4
T ₁₆	150	50	75	3.0:1:1.5	28.7	25.6	27.1	212.0	322.1	267.1	59.9	81.1	70.5
T ₁₇	150	62.5	50	2.4:1:0.8	26.2	32.1	29.1	213.9	324.8	269.4	59.5	85.2	72.4
T ₁₈	150	62.5	75	2.4:1:1.2	25.1	22.8	24.0	168.7	330.7	249.7	60.3	82.3	71.3
T ₁₉	0	0	0	0:0:0	27.8	9.7	18.8	101.9	136.7	119.3	37.6	29.2	33.4
S. Em±					1.8	3.2	1.8	12.5	13.6	9.2	3.7	5.3	3.2
C. D. at 5%					5.2	9.1	5.2	35.8	39.0	26.0	10.5	15.3	9.1

(150:62.5:50 kg N:P₂O₅:K₂O ha⁻¹) followed by T₁₂ (22.2 kg ha⁻¹), T₁₅ (22.0 kg ha⁻¹), T₁₆ (20.8 kg ha⁻¹) and T₁₄ (20.6 kg ha⁻¹). However, significantly lower sulphur uptake (8.9 kg ha⁻¹) by rice crop was noticed in treatment T₁₉ (control).

The sodium uptake by rice crop did not differ significantly over the control in the first season but it differed significantly in the second season (Table 4.31). Higher uptake of sodium was observed in treatment T₁₆ and T₁₅ (28.7 and 28.7 kg ha⁻¹, respectively) receiving NPK ratio of 2.4:1:0.8 (150:62.5:50) and 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) during both the years. The pooled analysis indicated that significantly higher sodium uptake by rice crop (29.6 kg ha⁻¹) was noticed in the treatment T₈ receiving NPK ratio of 3.3:1:2.0 (125:37.5:75 kg N:P₂O₅:K₂O ha⁻¹) followed by T₁₇ (29.1 kg ha⁻¹), T₁₅ (28.4 kg ha⁻¹), T₁₆ (27.1 kg ha⁻¹), T₆ (25.6 kg ha⁻¹), T₁₂ (25.4 kg ha⁻¹), T₁₃ (25.3 kg ha⁻¹), T₁₄ (24.7 kg ha⁻¹), T₉ (24.4 kg ha⁻¹) and T₁₀ (24.1 kg ha⁻¹). However, significantly lower sodium uptake (18.8 kg ha⁻¹) by rice crop was noticed in treatment T₁₉ (control).

4.9.3 Micronutrients

The results on uptake of Zn, Cu, Fe, Mn and B by rice crop varied significantly due to different levels and ratios of fertilizer compared to control and among different ratios at harvest (Table 4.39 and 4.40). The uptake of micronutrients except manganese by rice crop was higher in summer 2014 compared to *Kharif* 2013.

During 2013, higher uptake of Zn by rice crop was recorded in T₁₇ (213.9 g ha⁻¹) compared to all other treatments. But during 2014 higher Zn uptake was recorded in T₁₈ (330.7 g ha⁻¹). Pooled analysis of two years data showed significantly higher uptake of Zn (269.4 g ha⁻¹) by rice crop in the treatment T₁₇ that received NPK ratio of 2.4:1:0.8 (150:62.5:50 kg N:P₂O₅:K₂O ha⁻¹) followed by the treatment T₁₆ (267.1), T₁₅ (251.3 g ha⁻¹) and T₁₈ (249.7 g ha⁻¹). Lower uptake of Zn (119.3 g ha⁻¹) was observed in control.

The copper uptake by rice crop differed significantly over control during 2013 and 2014. Pooled analysis of two years data (2013 and 2014) showed that the copper uptake by the rice crop in control was 33.4 g ha⁻¹, which increased significantly due to application of NPK fertilizers and it ranged from 47.9 to 71.9 g ha⁻¹. The maximum

Table 4.40: Effect of nutrient levels and ratios on Fe, Mn and B uptake (g ha⁻¹) by rice crop in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K ratio	Fe			Mn			B		
	kg ha ⁻¹				2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	1538.2	1460.8	1499.5	1498.2	957.5	1227.9	139.8	136.3	138.0
T ₂	100	37.5	75	2.7:1:2.0	1532.5	1558.9	1545.7	1611.3	1107.6	1359.5	155.5	143.3	149.4
T ₃	100	50	50	2.0:1:1.0	1629.6	1917.4	1773.5	1759.3	1094.5	1426.9	133.2	144.2	138.7
T ₄	100	50	75	2.0:1:1.5	1554.5	1893.6	1724.0	1562.5	1115.3	1338.9	145.2	159.4	152.3
T ₅	100	62.5	50	1.6:1:0.8	1749.6	2105.5	1927.6	1661.6	1028.4	1345.0	158.3	174.9	166.6
T ₆	100	62.5	75	1.6:1:1.2	1893.6	2126.3	2009.9	1733.8	1122.2	1428.0	166.2	198.1	182.2
T ₇	125	37.5	50	3.3:1:1.3	1629.2	2113.9	1871.6	1679.2	1106.2	1392.7	164.1	176.9	170.5
T ₈	125	37.5	75	3.3:1:2.0	1769.6	2156.8	1963.2	1758.2	1094.0	1426.1	168.5	158.6	163.5
T ₉	125	50	50	2.5:1:1.0	1721.2	2234.9	1978.1	1872.8	1188.0	1530.4	144.4	200.9	172.6
T ₁₀	125	50	75	2.5:1:1.5	1729.3	2092.5	1910.9	1813.1	1262.5	1537.8	155.3	210.4	182.8
T ₁₁	125	62.5	50	2.0:1:0.8	1777.3	2270.6	2024.0	1871.8	1213.0	1542.4	165.8	191.1	178.5
T ₁₂	125	62.5	75	2.0:1:1.2	1978.9	2362.8	2170.8	1793.4	1260.7	1527.0	196.6	218.2	207.4
T ₁₃	150	37.5	50	4.0:1:1.3	1704.5	2449.4	2076.9	1768.9	1187.5	1478.2	180.4	195.1	187.8
T ₁₄	150	37.5	75	4.0:1:2.0	1854.1	2408.1	2131.1	1950.4	1268.8	1609.6	160.1	218.8	189.4
T ₁₅	150	50	50	3.0:1:1.0	1812.8	2647.1	2230.0	1692.9	1320.3	1506.6	173.7	247.5	210.6
T ₁₆	150	50	75	3.0:1:1.5	1891.8	2103.0	1997.4	1851.4	1406.7	1629.0	178.5	208.0	193.2
T ₁₇	150	62.5	50	2.4:1:0.8	1976.9	2440.9	2208.9	1906.5	1519.9	1713.2	188.3	216.3	202.3
T ₁₈	150	62.5	75	2.4:1:1.2	1798.2	2440.7	2119.5	1945.9	1409.2	1677.5	155.9	226.1	191.0
T ₁₉	0	0	0	0:0:0	1309.5	973.1	1141.3	984.7	547.0	765.8	104.8	81.8	93.3
S. Em±					122.1	179.0	108.3	137.2	59.1	74.7	12.7	13.3	9.2
C. D. at 5%					350.2	513.4	305.4	393.5	169.4	210.6	36.4	38.2	25.9

copper uptake was recorded in T₁₇ (71.9 g ha⁻¹) and it was on par with the treatments T₁₄, T₁₈, T₁₆, T₁₃, T₁₅, T₁₂ and T₁₀.

Nitrogen, phosphorus and potassium fertilization had significant effect on iron uptake by rice crop. The pooled analysis of two years data (2013 and 2014) showed that the treatment receiving NPK ratio of 3:1:1 (150:50:50) recorded highest iron uptake (2230.0 g ha⁻¹) and it was on par with all other treatments except T₁, T₂, T₃, T₄, T₇ and T₁₀. However, the lowest iron uptake was recorded in control (1141.3 g Fe ha⁻¹).

The manganese uptake was higher in rice crop grown during *Kharif* 2013 as compared to the crop grown during summer 2014. Application of nitrogen, phosphorus and potassium had significant effect on manganese uptake by rice crop over the control. Pooled analysis of two seasons data (2013 and 2014) showed that the treatment receiving NPK fertilizer ratio of 2.4:1:0.8 (150:62.5:50 kg N:P₂O₅:K₂O ha⁻¹) recorded highest manganese uptake (1713.2 g Mn ha⁻¹) and lowest manganese uptake was recorded in control (765.8 g Mn ha⁻¹).

The boron uptake of rice crop differed significantly due to application of nitrogen, phosphorus and potassium fertilizers at different levels and ratios over the control (T₁₉). Pooled analysis showed that boron uptake in the control was 93.3 g ha⁻¹, which increased significantly due to application of NPK fertilizers and it ranged from 138.0 to 210.6 g ha⁻¹. The maximum uptake was recorded in T₁₅ (210.6 g ha⁻¹) and it was on par with the treatments T₁₂, T₁₇, T₁₆, T₁₈, T₁₄ and T₁₃ (207.4, 202.3, 193.2, 191.0, 189.4 and 187.8 g B ha⁻¹, respectively).

4.9.4 Nutrient use efficiency after harvest of rice crop

The different levels and ratios of nitrogen, phosphorus and potassium had significant effect on N, P and K use efficiency during 2013 and 2014 (Table 4.41). The nutrient use efficiency was low during *Kharif* 2013 compared to summer 2014.

4.9.4.1 Nitrogen use efficiency (NUE)

The nitrogen use efficiency during *Kharif* 2013 varied from 0.17 kg N kg⁻¹ (T₁) to 0.33 kg N kg⁻¹ (T₁₂ and T₁₅) which increased to 0.44 to 0.69 kg N kg⁻¹ during summer

Table 4.41: Nutrient use efficiency of rice as influenced by nitrogen, phosphorus and potassium levels and ratios in gypsum amended sodic soil in rice-rice cropping system.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K ratio	N (kg N/ kg)			P ₂ O ₅ (kg P ₂ O ₅ / kg)			K ₂ O (kg K ₂ O/ kg)		
	kg ha ⁻¹				2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	0.17	0.44	0.31	0.16	0.24	0.20	0.47	0.64	0.56
T ₂	100	37.5	75	2.7:1:2.0	0.20	0.51	0.35	0.15	0.31	0.23	0.39	0.49	0.44
T ₃	100	50	50	2.0:1:1.0	0.23	0.59	0.41	0.16	0.24	0.20	0.55	0.78	0.66
T ₄	100	50	75	2.0:1:1.5	0.24	0.61	0.43	0.18	0.22	0.20	0.38	0.55	0.46
T ₅	100	62.5	50	1.6:1:0.8	0.25	0.61	0.43	0.07	0.16	0.12	0.65	0.86	0.76
T ₆	100	62.5	75	1.6:1:1.2	0.30	0.67	0.48	0.23	0.20	0.21	0.44	0.59	0.52
T ₇	125	37.5	50	3.3:1:1.3	0.22	0.57	0.40	0.23	0.40	0.32	0.58	0.82	0.70
T ₈	125	37.5	75	3.3:1:2.0	0.22	0.61	0.42	0.22	0.39	0.30	0.38	0.63	0.50
T ₉	125	50	50	2.5:1:1.0	0.24	0.63	0.44	0.25	0.35	0.30	0.72	0.93	0.82
T ₁₀	125	50	75	2.5:1:1.5	0.28	0.63	0.46	0.17	0.37	0.27	0.50	0.60	0.55
T ₁₁	125	62.5	50	2.0:1:0.8	0.31	0.66	0.48	0.17	0.22	0.20	0.73	0.88	0.80
T ₁₂	125	62.5	75	2.0:1:1.2	0.33	0.69	0.51	0.25	0.25	0.25	0.62	0.64	0.63
T ₁₃	150	37.5	50	4.0:1:1.3	0.24	0.60	0.42	0.29	0.41	0.35	0.62	1.07	0.84
T ₁₄	150	37.5	75	4.0:1:2.0	0.26	0.63	0.45	0.31	0.46	0.38	0.47	0.70	0.58
T ₁₅	150	50	50	3.0:1:1.0	0.33	0.69	0.51	0.28	0.47	0.38	0.73	1.28	1.00
T ₁₆	150	50	75	3.0:1:1.5	0.32	0.66	0.49	0.24	0.37	0.30	0.56	0.70	0.63
T ₁₇	150	62.5	50	2.4:1:0.8	0.29	0.62	0.45	0.25	0.29	0.27	0.87	1.07	0.97
T ₁₈	150	62.5	75	2.4:1:1.2	0.30	0.65	0.47	0.20	0.30	0.25	0.54	0.72	0.63
T ₁₉	0	0	0	0:0:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S. Em±					0.03	0.05	0.03	0.04	0.03	0.02	0.04	0.05	0.03
C. D. at 5%					0.10	0.14	0.08	0.10	0.08	0.06	0.12	0.16	0.10

2014 in the same treatments. Pooled analysis of two seasons data (2013 and 2014) showed that the N use efficiency varied from 0.31 (T_1) to 0.38 kg N kg⁻¹ (T_{12} and T_{15}). The highest NUE was recorded in T_{12} and T_{15} , which received NPK ratio of 2:1:1.2 (125:62.5:75 kg N:P₂O₅:K₂O ha⁻¹) and 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) and lowest was recorded in T_1 (100:37.5:50 kg NPK ha⁻¹)

4.9.4.2 Phosphorus use efficiency (PUE)

The phosphorus use efficiency was low in 2013 and it varied from 0.07 to 0.31 kg P₂O₅/ kg in treatments T_5 and T_{14} and it increased to 0.16 to 0.47 kg P₂O₅ kg⁻¹ during summer 2014. The pooled analysis data showed the P use efficiency varied from 0.12 (T_5) to 0.38 kg P₂O₅ kg⁻¹ (T_{14} and T_{15}). The highest PUE was recorded in T_{14} and T_{15} , which received NPK ratio 4:1:2 (150:37.5:75 kg N:P₂O₅:K₂O ha⁻¹) and 3:1:1 (150:50:50 kg N:P₂O₅:K₂O ha⁻¹) and it was on par with T_{13} and T_7 (0.35 and 0.32 kg P₂O₅ kg⁻¹, respectively). However, lowest PUE was recorded in T_1 (100:37.5:50 kg NPK ha⁻¹)

4.9.4.3 Potassium use efficiency (KUE)

The potassium use efficiency was less in first season compared to second season and it varied from 0.38 to 0.87 kg K₂O kg⁻¹ (T_4 and T_{17}) in 2013 and 0.49 to 1.28 kg K₂O kg⁻¹ (T_2 and T_{15}) in 2014. The pooled analysis data revealed that K use efficiency varied from 0.44 kg K₂O kg⁻¹ (T_2) to 1.00 kg K₂O kg⁻¹ (T_{15}) in different treatments. Significantly highest KUE was observed in T_{15} receiving NPK ratio 3:1:1 and it is on par with the treatment T_{17} receiving NPK ratio 2.4:1:0.8. However, lowest KUE was observed in T_2 receiving NPK ratio 2.7:1:2.

4.10 Chemical properties of soils (0-15cm and 15-30cm depth) after harvest of rice crop

4.10.1 Soil pH, ECe and organic carbon content of soils after crop harvest

The pH of soil was in general lower after the harvest of first crop and then it increased at harvest of second crop (Table 4.42 and 4.43). There was no significant difference in the soil pH among treatments during 2013 and 2014 due to nutrient levels and ratios. Application of nitrogen, phosphorus and potassium significantly decreased the

Table 4.42: Effect of NPK levels and ratios on soil pH, electrical conductivity and organic carbon content of soil (0-15 cm) after the harvest of rice crop in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K	pH (1:2.5)			ECe (dS m ⁻¹)			OC (g kg ⁻¹)		
	kg ha ⁻¹			ratio	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T₁	100	37.5	50	2.7:1:1.3	7.9	8.1	8.0	4.3	2.9	3.6	6.8	5.7	6.2
T₂	100	37.5	75	2.7:1:2.0	7.8	7.9	7.9	5.2	3.1	4.1	6.9	5.7	6.3
T₃	100	50	50	2.0:1:1.0	7.8	8.1	7.9	5.3	2.4	3.8	7.0	6.1	6.5
T₄	100	50	75	2.0:1:1.5	8.0	7.9	7.9	4.9	2.9	3.9	6.4	6.3	6.3
T₅	100	62.5	50	1.6:1:0.8	7.8	8.1	8.0	4.4	2.3	3.4	7.1	6.0	6.6
T₆	100	62.5	75	1.6:1:1.2	7.7	8.1	7.9	5.4	2.4	3.9	7.1	5.6	6.4
T₇	125	37.5	50	3.3:1:1.3	7.7	8.1	7.9	5.1	2.3	3.7	6.1	5.7	5.9
T₈	125	37.5	75	3.3:1:2.0	8.0	8.1	8.0	4.2	2.2	3.2	6.0	5.4	5.7
T₉	125	50	50	2.5:1:1.0	7.7	7.8	7.7	5.4	2.8	4.1	6.2	5.7	5.9
T₁₀	125	50	75	2.5:1:1.5	7.7	8.0	7.9	4.4	2.6	3.5	7.3	6.0	6.7
T₁₁	125	62.5	50	2.0:1:0.8	7.8	8.1	7.9	4.6	2.3	3.4	6.5	5.9	6.2
T₁₂	125	62.5	75	2.0:1:1.2	7.7	8.0	7.8	5.4	2.8	4.1	6.2	6.5	6.3
T₁₃	150	37.5	50	4.0:1:1.3	7.7	8.1	7.9	5.4	2.6	4.0	7.4	5.9	6.6
T₁₄	150	37.5	75	4.0:1:2.0	7.9	8.1	8.0	4.7	2.6	3.6	6.5	5.9	6.2
T₁₅	150	50	50	3.0:1:1.0	7.8	7.9	7.8	4.2	2.6	3.4	7.2	6.3	6.8
T₁₆	150	50	75	3.0:1:1.5	7.7	7.8	7.8	4.5	3.1	3.8	6.5	5.2	5.8
T₁₇	150	62.5	50	2.4:1:0.8	7.8	8.0	7.9	4.2	2.6	3.4	6.6	5.8	6.2
T₁₈	150	62.5	75	2.4:1:1.2	7.9	8.1	8.0	5.2	2.6	3.9	6.5	5.4	6.0
T₁₉	0	0	0	0:0:0	8.0	8.0	8.0	3.8	2.1	2.9	5.6	4.3	5.0
S. Em±					0.1	0.1	0.1	0.3	0.1	0.2	0.5	0.4	0.3
C. D. at 5%					NS	NS	NS	0.9	0.4	0.5	NS	NS	0.8

Table 4.43: Effect of NPK levels and ratios on soil pH, electrical conductivity and organic carbon content of soil (15-30 cm) after the harvest of rice crop in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K	pH (1:2.5)			ECe (dS m ⁻¹)			OC (g kg ⁻¹)		
	kg ha ⁻¹			ratio	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	8.6	8.7	8.7	4.5	3.0	3.7	6.4	3.8	5.1
T ₂	100	37.5	75	2.7:1:2.0	8.6	8.8	8.7	4.1	3.3	3.7	6.4	3.4	4.9
T ₃	100	50	50	2.0:1:1.0	8.6	9.0	8.8	4.9	3.3	4.1	6.1	3.5	4.8
T ₄	100	50	75	2.0:1:1.5	8.3	8.9	8.6	4.3	2.9	3.6	6.3	4.7	5.5
T ₅	100	62.5	50	1.6:1:0.8	8.5	8.9	8.7	4.4	3.1	3.8	6.7	4.5	5.6
T ₆	100	62.5	75	1.6:1:1.2	8.6	9.0	8.8	5.1	3.3	4.2	6.6	4.1	5.3
T ₇	125	37.5	50	3.3:1:1.3	8.5	8.9	8.7	4.2	3.0	3.6	5.7	4.1	4.9
T ₈	125	37.5	75	3.3:1:2.0	8.5	8.8	8.7	4.2	3.3	3.8	5.7	4.6	5.2
T ₉	125	50	50	2.5:1:1.0	8.2	8.8	8.5	5.8	3.3	4.5	5.7	4.4	5.1
T ₁₀	125	50	75	2.5:1:1.5	8.6	8.7	8.6	4.2	3.6	3.9	6.0	4.1	5.1
T ₁₁	125	62.5	50	2.0:1:0.8	8.5	8.9	8.7	4.0	3.1	3.5	5.9	5.2	5.6
T ₁₂	125	62.5	75	2.0:1:1.2	8.5	8.6	8.6	5.2	3.5	4.3	6.5	4.1	5.3
T ₁₃	150	37.5	50	4.0:1:1.3	8.4	8.8	8.6	5.9	3.6	4.7	5.9	4.1	5.0
T ₁₄	150	37.5	75	4.0:1:2.0	8.5	8.8	8.7	5.0	3.6	4.3	5.9	3.8	4.9
T ₁₅	150	50	50	3.0:1:1.0	8.2	8.8	8.5	5.7	2.7	4.2	6.3	5.0	5.6
T ₁₆	150	50	75	3.0:1:1.5	8.3	8.7	8.5	5.0	3.6	4.3	4.8	4.4	4.6
T ₁₇	150	62.5	50	2.4:1:0.8	8.5	8.7	8.6	5.1	3.6	4.4	5.8	3.8	4.8
T ₁₈	150	62.5	75	2.4:1:1.2	8.2	8.8	8.5	5.5	3.0	4.2	6.1	4.6	5.3
T ₁₉	0	0	0	0:0:0	8.7	8.7	8.8	3.7	2.3	3.0	5.3	2.6	4.0
S. Em±					0.1	0.1	0.1	0.4	0.3	0.2	0.3	0.3	0.2
C. D. at 5%					0.3	NS	0.2	1.1	NS	0.7	0.9	0.9	0.6

pH of soil over the initial value of 8.6. Pooled analysis of two season's data (2013 and 2014) showed that pH of surface soil samples ranged from 7.7 to 8.0. Soil pH has increased in the subsurface layer compared to surface layer in both the season. The pH of soil in summer 2014 increased compared to *Kharif* 2013. Pooled analysis of two years (2013 and 2014) data revealed that soil pH increased from 8.6 (initial) to 8.8 in control and 8.5 to 8.8 in all other treatments.

Application of different levels and ratios of nitrogen, phosphorus and potassium had significant effect on electrical conductivity of saturation extract. The electrical conductivity of surface soil samples ranged from 2.9 to 4.1 dS m⁻¹. Among the different treatments, the treatment receiving different levels and ratios of NPK recorded maximum electrical conductivity (3.4 to 4.1 dS m⁻¹) of soil. Lowest ECe was observed in control (2.9 dS m⁻¹). In subsurface soil the ECe has decreased in both the seasons. Pooled analysis of two years (2013 and 2014) results revealed that the ECe has decreased from 3.2 to 2.9 dS m⁻¹ in control and it ranged from 3.2 to 4.1 dS m⁻¹ in rest of the treatments.

Organic carbon content of soil was not significantly influenced by application of different levels and ratios of nutrients. The organic carbon content of surface soil samples ranged from 4.8 to 6.5 g kg⁻¹. Among the different treatments, the treatment receiving NPK ratio of 2:1:1.2 (T₁₂) recorded maximum OC content of 6.5 g kg⁻¹. However, lowest OC content was recorded in control (4.8 g kg⁻¹). Slight decrease in organic carbon content was observed in subsurface compared to surface horizon. Pooled analysis of two years (2013 and 2014) data revealed that the organic carbon content of soil ranged from 5.0 to 6.8 g kg⁻¹.

4.10.2 Available nutrients status in soil after harvest of rice crop

4.10.2.1 Available nitrogen (kg N ha⁻¹)

The available nitrogen, phosphorus and potassium content of soil were higher in most of the treatments during summer 2014 compared to *Kharif* 2013 (Table 4.44 and 4.45).

Table 4.44: Effect of NPK levels and ratios on available N, P and K content (kg ha⁻¹) of soil (0-15 cm) after the harvest of rice crop in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K	Available- N			Available- P ₂ O ₅			Available- K ₂ O		
	kg ha ⁻¹			ratio	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	312.3	311.1	311.7	22.3	61.5	41.9	277.2	240.0	258.6
T ₂	100	37.5	75	2.7:1:2.0	312.3	300.4	306.4	38.1	64.4	51.3	287.2	225.0	256.1
T ₃	100	50	50	2.0:1:1.0	319.9	300.4	310.2	34.6	57.8	46.2	281.2	232.8	257.0
T ₄	100	50	75	2.0:1:1.5	297.9	304.8	301.4	26.8	62.9	44.9	287.9	226.2	257.0
T ₅	100	62.5	50	1.6:1:0.8	361.3	304.8	333.0	28.9	61.1	45.0	284.8	247.1	265.9
T ₆	100	62.5	75	1.6:1:1.2	351.2	288.5	319.9	33.2	63.9	48.6	300.8	241.8	271.3
T ₇	125	37.5	50	3.3:1:1.3	318.0	329.3	323.6	28.4	57.7	43.0	258.0	243.6	250.8
T ₈	125	37.5	75	3.3:1:2.0	285.4	304.8	295.1	33.3	54.9	44.1	263.1	213.0	238.0
T ₉	125	50	50	2.5:1:1.0	303.6	313.6	308.6	38.6	62.1	50.4	260.4	231.0	245.7
T ₁₀	125	50	75	2.5:1:1.5	360.6	318.0	339.3	30.7	68.0	49.4	315.2	251.9	283.6
T ₁₁	125	62.5	50	2.0:1:0.8	331.1	308.0	319.5	24.0	67.5	45.8	294.8	239.4	267.1
T ₁₂	125	62.5	75	2.0:1:1.2	321.8	310.5	316.1	30.5	65.6	48.1	314.9	251.6	283.3
T ₁₃	150	37.5	50	4.0:1:1.3	339.9	316.7	328.3	37.8	57.0	47.4	301.2	252.0	276.6
T ₁₄	150	37.5	75	4.0:1:2.0	337.4	308.6	323.0	23.5	56.7	40.1	316.4	246.0	281.2
T ₁₅	150	50	50	3.0:1:1.0	328.7	297.9	313.3	27.2	66.4	46.8	316.4	230.4	273.4
T ₁₆	150	50	75	3.0:1:1.5	351.9	291.6	321.8	32.0	61.7	46.9	304.4	244.8	274.6
T ₁₇	150	62.5	50	2.4:1:0.8	326.8	291.0	308.9	27.5	56.1	41.8	282.0	220.9	251.5
T ₁₈	150	62.5	75	2.4:1:1.2	313.6	299.8	306.7	23.3	75.2	49.3	264.4	231.0	247.7
T ₁₉	0	0	0	0:0:0	297.9	282.2	290.1	20.6	46.3	33.5	190.4	152.0	171.2
S. Em±					11.2	6.6	6.5	2.6	4.2	2.5	13.8	9.0	8.2
C. D. at 5%					32.2	18.8	18.4	7.6	12.1	7.0	39.5	25.8	23.2

Table 4.45: Effect of NPK levels and ratios on available N, P and K content (kg ha⁻¹) of soil at 15-30 cm depth after the harvest of rice crop in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K	Available- N			Available- P ₂ O ₅			Available- K ₂ O		
	kg ha ⁻¹			ratio	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	249.6	235.8	242.7	25.8	26.3	26.1	284.8	212.4	248.6
T ₂	100	37.5	75	2.7:1:2.0	225.2	205.1	215.1	23.0	22.7	22.8	249.6	199.1	224.4
T ₃	100	50	50	2.0:1:1.0	230.2	203.2	216.7	22.5	24.5	23.5	320.4	225.0	272.7
T ₄	100	50	75	2.0:1:1.5	264.7	200.1	232.4	30.8	22.1	26.5	260.1	197.1	228.6
T ₅	100	62.5	50	1.6:1:0.8	254.6	249.0	251.8	26.2	21.2	23.7	303.2	213.6	258.4
T ₆	100	62.5	75	1.6:1:1.2	253.4	206.3	229.9	29.9	23.7	26.8	292.8	198.6	245.7
T ₇	125	37.5	50	3.3:1:1.3	231.0	217.0	224.0	24.6	26.5	25.6	274.8	206.4	240.6
T ₈	125	37.5	75	3.3:1:2.0	259.7	255.9	257.8	31.2	27.2	29.2	306.4	216.0	261.2
T ₉	125	50	50	2.5:1:1.0	252.1	247.7	249.9	31.9	31.9	31.9	295.2	213.0	254.1
T ₁₀	125	50	75	2.5:1:1.5	232.1	247.7	239.9	25.4	26.3	25.9	318.4	215.4	266.9
T ₁₁	125	62.5	50	2.0:1:0.8	276.0	231.4	253.7	23.4	24.2	23.8	299.6	195.0	247.3
T ₁₂	125	62.5	75	2.0:1:1.2	257.2	276.0	266.6	32.9	32.4	32.6	334.8	246.6	290.7
T ₁₃	150	37.5	50	4.0:1:1.3	236.5	230.2	233.3	30.2	21.8	26.0	298.0	232.2	265.1
T ₁₄	150	37.5	75	4.0:1:2.0	226.6	279.1	252.8	35.7	28.2	32.0	347.9	226.8	287.3
T ₁₅	150	50	50	3.0:1:1.0	280.4	241.5	260.9	35.1	31.5	33.3	301.3	223.2	262.3
T ₁₆	150	50	75	3.0:1:1.5	266.6	242.7	254.6	32.4	31.6	32.0	321.2	215.7	268.5
T ₁₇	150	62.5	50	2.4:1:0.8	234.6	238.3	236.5	26.2	28.9	27.5	298.0	207.3	252.7
T ₁₈	150	62.5	75	2.4:1:1.2	238.3	245.9	242.1	35.6	26.8	31.2	279.2	217.2	248.2
T ₁₉	0	0	0	0:0:0	168.5	142.0	155.3	18.3	16.4	17.3	202.1	164.3	183.2
S. Em±					15.1	18.2	11.8	3.3	2.6	2.1	17.2	11.0	10.2
C. D. at 5%					43.36	52.14	33.3	9.4	7.3	5.8	49.2	31.4	28.7

Pooled analysis of data of two seasons (2013 and 2014) revealed that the available nitrogen content of soil after harvest of rice crop differed significantly due to different levels and ratios of nitrogen, phosphorus and potassium application. Among different treatments, the treatment receiving NPK ratio of 2.5:1:1.5 recorded maximum available nitrogen ($339.3 \text{ kg N ha}^{-1}$) in soil. Lowest available nitrogen was recorded in T₁₉ treatment ($290.1 \text{ kg N ha}^{-1}$) and in other treatments it ranged from 295.1 to $333.0 \text{ kg N ha}^{-1}$. The available nitrogen content of subsurface soil was low compared to surface soil. The pooled analysis of two year data revealed that available nitrogen in subsurface soil varied from 155.3 to 260.9 kg ha^{-1} .

4.10.2.2 Available phosphorus ($\text{kg P}_2\text{O}_5 \text{ ha}^{-1}$)

The available phosphorus content of soil after harvest of rice crop differed significantly due to nitrogen, phosphorus and potassium fertilization (Table 4.44 and 4.45). Pooled analysis of two seasons data (2013 and 2014) showed that the treatment receiving NPK ratio of 2.7:1:2 recorded maximum available phosphorus ($51.3 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$) and it ranged from 40.1 to $50.4 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ in other treatments. Lowest available phosphorus content was observed in control ($33.5 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$). The available phosphorus content of subsurface soil was less compared to surface soil. The pooled analysis of two year analysis data revealed that available phosphorus in soil varied from 17.3 to 33.3 kg ha^{-1} .

4.10.2.3 Available potassium ($\text{kg K}_2\text{O ha}^{-1}$)

Pooled analysis of data of two years (2013 and 2014) revealed that the available potassium content of soil after harvest of rice crop differed significantly due to nutrient levels and ratios (Table 4.44 and 4.45). It ranged from 247.7 to $283.3 \text{ kg K}_2\text{O ha}^{-1}$ in different treatments. The treatment receiving NPK ratio of 2.5:1:1.5 recorded maximum available potassium ($283.6 \text{ kg K}_2\text{O ha}^{-1}$). Lowest available potassium was recorded in control ($171.2 \text{ kg K}_2\text{O ha}^{-1}$). The available potassium content of subsurface soil was low compared to surface soil. The pooled analysis of two year data revealed that available potassium in soil varied from 183.2 to 290.7 kg ha^{-1} .

4.10.2.4 Exchangeable calcium ($\text{cmol}(\text{p}^+)\text{kg}^{-1}$)

The exchangeable calcium did not show any significant difference between the treatments during 2013 and 2014 (Table 4.46 and 4.47). However, pooled analysis of data of two years (2013 and 2014) revealed that higher exchangeable calcium content of soil was observed in treatments T_{11} receiving NPK ratio 2.5:1:0.8, T_{13} receiving NPK ratio 4.0:1:1.3 and T_{16} receiving NPK ratio 3.0:1:1.5 ($8.7 \text{ cmol}(\text{p}^+)\text{kg}^{-1}$) compared to all other treatments. The lowest exch. Ca was recorded in control ($6.1 \text{ cmol}(\text{p}^+)\text{kg}^{-1}$) and it ranged from 6.8 to $8.5 \text{ cmol}(\text{p}^+)\text{kg}^{-1}$ in all other treatments. The exchangeable calcium content did not vary much compared to surface horizon both during *Kharif* 2013 and summer 2014. Pooled analysis of 2013 and 2014 data showed calcium content increased over the control.

4.10.2.5 Exchangeable magnesium ($\text{cmol}(\text{p}^+)\text{kg}^{-1}$)

The pooled analysis (2013 and 2014) revealed that higher exchangeable magnesium content of soil was recorded in treatment T_3 receiving NPK ratio 2.7:1:2 ($4.3 \text{ cmol}(\text{p}^+)\text{kg}^{-1}$) and it ranged from 3.2 to $4.2 \text{ cmol}(\text{p}^+)\text{kg}^{-1}$ in other treatments receiving different nutrient ratios and levels (Table 4.46 and 4.47). However, lower content of exchangeable magnesium content ($3.2 \text{ cmol}(\text{p}^+)\text{kg}^{-1}$) was recorded in control (T_{19}). Slight decrease in exchangeable magnesium content of soil was observed in summer 2014 compared to *Kharif* 2013. Pooled analysis of 2013 and 2014 data on magnesium content showed an increase over the initial.

4.10.2.6 Available sulphur (mg kg^{-1})

The available sulphur content of soil after harvest of rice crop differed significantly due to nitrogen, phosphorus and potassium fertilization (Table 4.46 and 4.47). Pooled analysis of data of two years (2013 and 2014) revealed that higher available sulphur content of soil (191.1 mg kg^{-1}) was observed in treatment receiving NPK ratio of 4:1:1.3 and it ranged from 128.5 to 188.7 mg kg^{-1} in rest of treatments. Lowest available sulphur content was observed in control (84.3 mg kg^{-1}). The available sulphur content of soil was lower in all treatments during summer 2014 compared to *Kharif* 2013. Pooled

Table 4.46: Effect of NPK levels and ratios on exchangeable-Ca, Mg and available S content of soil (0-15 cm) after the harvest of rice crop in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K	Exch. Ca (cmol(p ⁺)kg ⁻¹)			Exch. Mg (cmol(p ⁺)kg ⁻¹)			Available S (mg kg ⁻¹)		
	kg ha ⁻¹			ratio	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	7.7	8.4	8.1	4.3	3.5	3.9	216.1	72.9	144.5
T ₂	100	37.5	75	2.7:1:2.0	7.6	8.1	7.9	4.1	3.2	3.6	236.9	78.5	157.7
T ₃	100	50	50	2.0:1:1.0	7.1	7.9	7.5	4.9	3.8	4.3	219.8	70.3	145.0
T ₄	100	50	75	2.0:1:1.5	6.4	7.8	7.1	5.3	2.8	4.0	197.7	75.8	136.7
T ₅	100	62.5	50	1.6:1:0.8	6.5	8.6	7.5	5.2	2.6	3.9	203.6	73.2	138.4
T ₆	100	62.5	75	1.6:1:1.2	7.9	7.5	7.7	4.1	3.7	3.9	271.6	74.4	173.0
T ₇	125	37.5	50	3.3:1:1.3	8.9	8.2	8.5	3.7	3.5	3.6	270.4	59.5	165.0
T ₈	125	37.5	75	3.3:1:2.0	6.3	7.4	6.8	5.0	3.2	4.1	189.9	67.1	128.5
T ₉	125	50	50	2.5:1:1.0	6.6	8.2	7.4	4.9	3.2	4.0	248.9	81.7	165.3
T ₁₀	125	50	75	2.5:1:1.5	9.0	8.5	8.7	4.6	3.3	3.9	193.6	92.9	143.3
T ₁₁	125	62.5	50	2.0:1:0.8	7.8	9.2	8.5	4.1	3.0	3.5	189.2	73.5	131.3
T ₁₂	125	62.5	75	2.0:1:1.2	7.6	8.9	8.2	4.8	3.1	3.9	283.2	94.3	188.7
T ₁₃	150	37.5	50	4.0:1:1.3	9.0	8.5	8.7	3.6	3.0	3.3	290.3	91.8	191.1
T ₁₄	150	37.5	75	4.0:1:2.0	8.3	8.8	8.5	3.6	3.2	3.4	204.4	84.1	144.2
T ₁₅	150	50	50	3.0:1:1.0	8.6	8.3	8.5	3.9	3.1	3.5	239.2	87.0	163.1
T ₁₆	150	50	75	3.0:1:1.5	8.7	8.8	8.7	3.9	3.4	3.6	214.5	95.9	155.2
T ₁₇	150	62.5	50	2.4:1:0.8	6.2	7.5	6.8	5.3	3.1	4.2	184.1	90.5	137.3
T ₁₈	150	62.5	75	2.4:1:1.2	6.8	8.8	7.8	4.1	3.0	3.5	188.6	89.1	138.8
T ₁₉	0	0	0	0:0:0	5.4	6.9	6.1	3.7	2.7	3.2	99.3	69.3	84.3
S. Em±					0.5	0.4	0.3	0.4	0.2	0.2	25.1	5.5	12.8
C. D. at 5%					1.5	1.1	0.9	1.0	0.6	06	71.9	15.7	36.2

Table 4.47: Effect of NPK levels and ratios on exchangeable-Ca, Mg and available S content of soil (15-30 cm) after the harvest of rice crop in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K	Exch. Ca (cmol(p ⁺)kg ⁻¹)			Exch. Mg (cmol(p ⁺)kg ⁻¹)			Available S (mg kg ⁻¹)		
	kg ha ⁻¹			ratio	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T₁	100	37.5	50	2.7:1:1.3	8.9	8.5	8.7	4.0	4.0	4.0	72.8	47.8	60.3
T₂	100	37.5	75	2.7:1:2.0	8.1	8.1	8.1	3.3	3.3	3.3	73.7	46.1	59.9
T₃	100	50	50	2.0:1:1.0	8.8	9.1	8.9	4.5	3.5	4.0	70.5	50.2	60.3
T₄	100	50	75	2.0:1:1.5	8.5	8.8	8.6	3.6	3.5	3.6	78.0	44.4	61.2
T₅	100	62.5	50	1.6:1:0.8	8.3	8.7	8.5	4.2	3.6	3.9	72.7	44.4	58.6
T₆	100	62.5	75	1.6:1:1.2	8.3	8.0	8.1	3.5	4.2	3.8	72.2	50.0	61.1
T₇	125	37.5	50	3.3:1:1.3	8.3	8.3	8.3	3.7	4.3	4.0	70.5	47.6	59.0
T₈	125	37.5	75	3.3:1:2.0	9.1	8.9	9.0	3.8	3.8	3.8	71.2	49.2	60.2
T₉	125	50	50	2.5:1:1.0	9.0	9.4	9.2	3.4	3.3	3.3	72.0	50.3	61.2
T₁₀	125	50	75	2.5:1:1.5	8.5	9.1	8.8	4.3	4.1	4.2	86.3	44.1	65.2
T₁₁	125	62.5	50	2.0:1:0.8	8.8	9.3	9.1	3.8	3.4	3.6	82.7	48.1	65.4
T₁₂	125	62.5	75	2.0:1:1.2	8.0	9.0	8.5	4.5	3.8	4.2	84.0	52.2	68.1
T₁₃	150	37.5	50	4.0:1:1.3	8.8	9.4	9.1	4.6	4.1	4.3	78.5	52.9	65.7
T₁₄	150	37.5	75	4.0:1:2.0	8.2	9.5	8.8	4.7	4.0	4.4	78.3	55.7	67.0
T₁₅	150	50	50	3.0:1:1.0	8.6	8.9	8.7	3.7	4.4	4.0	87.7	47.6	67.6
T₁₆	150	50	75	3.0:1:1.5	8.2	8.0	8.1	4.4	3.5	3.9	60.3	47.0	53.7
T₁₇	150	62.5	50	2.4:1:0.8	8.3	8.8	8.6	3.5	2.7	3.1	83.7	46.4	65.0
T₁₈	150	62.5	75	2.4:1:1.2	8.0	9.0	8.5	3.8	3.4	3.6	81.3	50.1	65.7
T₁₉	0	0	0	0:0:0	6.8	7.5	7.2	2.6	2.8	2.7	69.3	37.6	53.5
S. Em±					0.5	0.6	0.4	0.3	0.4	0.2	9.1	5.1	5.2
C. D. at 5%					1.3	1.6	1.0	0.8	1.1	0.7	26.1	14.8	14.8

analysis of 2013 and 2014 data revealed that sulphur content of soil has increased over the initial value.

4.10.2.7 Exchangeable sodium ($\text{cmol}(\text{p}^+)\text{kg}^{-1}$)

Pooled analysis of data of two years (2013 and 2014) revealed that treatment T_{18} receiving NPK ratio 2.4:1:1.2 showed significantly higher exch. Na ($2.11 \text{ cmol}(\text{p}^+)\text{kg}^{-1}$) content of soil and it ranged from 1.66 to $2.07 \text{ cmol}(\text{p}^+)\text{kg}^{-1}$ (Table 4.48 and 4.49). However, significantly lower sodium content ($1.60 \text{ cmol}(\text{p}^+)\text{kg}^{-1}$) of soil was observed in the treatment T_{19} receiving only gypsum and farm yard manure without NPK fertilizer.

In subsurface, the initial exch. Na content was $20.32 \text{ cmol}(\text{p}^+)\text{kg}^{-1}$ which increased to as high as $41.0 \text{ cmol}(\text{p}^+)\text{kg}^{-1}$ in *Kharif* 2013 and then decreased to $36.0 \text{ cmol}(\text{p}^+)\text{kg}^{-1}$ in summer 2014. Pooled analysis of 2013 and 2014 data revealed that sodium content was increased over the initial value.

4.10.2.8 DTPA extractable zinc (mg kg^{-1})

The different levels and ratios of nitrogen, phosphorus and potassium had significant effect on DTPA zinc content of soil (Table 4.48 and 4.49). Pooled analysis of data of two years revealed that, the treatment receiving NPK fertilizer ratio of 4.0:1:2.0 recorded highest available zinc content (4.55 mg kg^{-1}), whereas, the lowest content was recorded in control (2.80 mg kg^{-1}). However, it ranged from 3.63 to 4.34 mg kg^{-1} . In subsurface soil the zinc content has decreased compared to surface horizon and it varied from 1.26 mg kg^{-1} in control to 1.95 mg kg^{-1} in the treatment T_{12} .

4.10.2.9 DTPA extractable copper (mg kg^{-1})

Pooled analysis of data of two years (2013 and 2014) revealed that different levels and ratios of nitrogen, phosphorus and potassium had significant effect on DTPA copper content of soil (Table 4.48 and 4.49). Among the different treatments, the treatment receiving NPK fertilizer ratio of 4.0:1:1.3 recorded highest available copper content (4.39 mg kg^{-1}). However, it ranged from 3.53 to 4.32 mg kg^{-1} in the other treatments and lowest available copper content (2.85 mg kg^{-1}) was recorded in control. The copper content of

Table 4.48: Effect of NPK levels and ratios on exchangeable sodium and DTPA extractable zinc and copper content of soil (0-15 cm) after the harvest of rice crop grown in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K	Exch. Na (cmol(p ⁺)kg ⁻¹)			Zinc (mg kg ⁻¹)			Copper (mg kg ⁻¹)		
	kg ha ⁻¹			ratio	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T₁	100	37.5	50	2.7:1:1.3	2.02	2.07	2.04	3.01	4.96	3.99	3.94	3.67	3.81
T₂	100	37.5	75	2.7:1:2.0	1.95	1.75	1.85	3.81	4.19	4.00	4.01	3.55	3.78
T₃	100	50	50	2.0:1:1.0	1.72	2.43	2.07	3.24	4.48	3.86	4.53	4.11	4.32
T₄	100	50	75	2.0:1:1.5	2.16	1.55	1.85	3.79	4.30	4.04	3.99	3.76	3.88
T₅	100	62.5	50	1.6:1:0.8	1.73	1.80	1.76	3.38	5.29	4.34	4.12	4.04	4.08
T₆	100	62.5	75	1.6:1:1.2	1.89	1.95	1.92	3.63	4.65	4.14	4.13	3.86	3.99
T₇	125	37.5	50	3.3:1:1.3	1.78	1.99	1.88	3.01	5.24	4.13	3.76	4.20	3.98
T₈	125	37.5	75	3.3:1:2.0	1.75	1.58	1.67	3.28	3.98	3.63	3.47	3.60	3.53
T₉	125	50	50	2.5:1:1.0	1.69	1.73	1.71	4.09	4.30	4.20	3.94	3.90	3.92
T₁₀	125	50	75	2.5:1:1.5	1.70	1.97	1.83	4.24	3.82	4.03	4.62	4.14	4.38
T₁₁	125	62.5	50	2.0:1:0.8	1.73	1.89	1.81	3.86	3.67	3.76	4.21	3.66	3.93
T₁₂	125	62.5	75	2.0:1:1.2	1.89	1.92	1.90	4.10	4.88	4.49	4.01	4.10	4.05
T₁₃	150	37.5	50	4.0:1:1.3	1.76	2.04	1.90	3.91	4.47	4.19	4.65	4.12	4.39
T₁₄	150	37.5	75	4.0:1:2.0	1.97	2.11	2.04	3.82	5.28	4.55	4.57	3.96	4.27
T₁₅	150	50	50	3.0:1:1.0	1.92	1.62	1.77	3.95	4.09	4.02	4.32	3.95	4.13
T₁₆	150	50	75	3.0:1:1.5	1.78	1.59	1.69	4.14	4.39	4.26	4.05	3.66	3.85
T₁₇	150	62.5	50	2.4:1:0.8	1.76	1.57	1.66	3.39	5.44	4.41	3.77	3.60	3.68
T₁₈	150	62.5	75	2.4:1:1.2	2.22	1.99	2.11	3.55	4.00	3.77	4.05	3.85	3.95
T₁₉	0	0	0	0:0:0	1.58	1.63	1.60	2.23	3.37	2.80	2.69	3.00	2.85
S. Em±					0.11	0.11	0.08	0.22	0.37	0.22	0.19	0.15	0.12
C. D. at 5%					0.31	0.31	0.21	0.64	1.05	0.61	0.54	0.43	0.34

Table 4.49: Effect of NPK levels and ratios on exchangeable sodium and DTPA extractable zinc and copper content of soil (15-30 cm) after the harvest of rice crop grown in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K	Exch. Na (cmol(p ⁺)kg ⁻¹)			Zinc (mg kg ⁻¹)			Copper (mg kg ⁻¹)		
	kg ha ⁻¹			ratio	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T₁	100	37.5	50	2.7:1:1.3	3.77	3.37	3.57	2.01	1.77	1.89	3.36	3.84	3.60
T₂	100	37.5	75	2.7:1:2.0	2.78	2.44	2.61	1.91	1.41	1.66	3.24	3.42	3.33
T₃	100	50	50	2.0:1:1.0	4.59	3.58	4.09	1.80	1.27	1.53	4.04	3.83	3.93
T₄	100	50	75	2.0:1:1.5	3.80	2.43	3.11	2.01	1.43	1.72	4.04	3.27	3.65
T₅	100	62.5	50	1.6:1:0.8	3.42	2.96	3.19	2.06	1.70	1.88	3.93	3.97	3.95
T₆	100	62.5	75	1.6:1:1.2	3.84	3.26	3.55	1.69	1.47	1.58	3.65	3.52	3.58
T₇	125	37.5	50	3.3:1:1.3	3.26	3.18	3.22	1.92	1.33	1.63	3.56	3.51	3.54
T₈	125	37.5	75	3.3:1:2.0	3.56	3.09	3.33	1.96	1.41	1.69	3.91	4.29	4.10
T₉	125	50	50	2.5:1:1.0	3.34	3.02	3.18	1.90	1.71	1.80	3.63	3.70	3.66
T₁₀	125	50	75	2.5:1:1.5	3.62	3.14	3.38	1.78	1.27	1.52	3.48	3.87	3.67
T₁₁	125	62.5	50	2.0:1:0.8	3.42	3.18	3.30	2.18	1.38	1.78	4.28	3.68	3.98
T₁₂	125	62.5	75	2.0:1:1.2	3.73	2.94	3.34	2.13	1.76	1.95	3.61	3.65	3.63
T₁₃	150	37.5	50	4.0:1:1.3	3.67	3.31	3.49	1.91	1.44	1.67	4.09	3.92	4.00
T₁₄	150	37.5	75	4.0:1:2.0	3.90	3.42	3.66	1.59	1.73	1.66	3.71	4.34	4.03
T₁₅	150	50	50	3.0:1:1.0	3.34	2.83	3.09	2.06	1.63	1.85	4.18	3.79	3.99
T₁₆	150	50	75	3.0:1:1.5	3.49	2.35	2.92	1.68	1.42	1.55	3.64	3.14	3.39
T₁₇	150	62.5	50	2.4:1:0.8	3.57	2.33	2.95	1.70	1.46	1.58	3.92	3.61	3.76
T₁₈	150	62.5	75	2.4:1:1.2	3.46	3.16	3.31	1.71	1.57	1.64	3.41	3.64	3.52
T₁₉	0	0	0	0:0:0	3.81	2.99	3.40	1.43	1.09	1.26	3.05	2.83	2.94
S. Em±					0.25	0.15	0.15	0.25	0.22	0.17	0.4	0.3	0.26
C. D. at 5%					0.72	0.44	0.42	NS	NS	NS	1.14	1.00	0.74

subsurface soil was low compared to surface soil and it varied from 2.94 mg kg⁻¹ in control to 4.10 mg kg⁻¹ in T₈.

4.10.2.10 DTPA extractable iron (mg kg⁻¹)

The nitrogen, phosphorus and potassium levels and ratios had significant effect on DTPA iron content of soil (Table 4.50 and 4.51). Pooled analysis of data of two years (2013 and 2014) revealed that the treatment receiving NPK ratio of 4:1:1.3 (150:37.5:50) recorded the highest available iron content (26.13 mg kg⁻¹). Whereas, the lowest value (17.63 mg kg⁻¹) was recorded in control and in all other NPK fertilizer ratios, it ranged from 22.68 to 26.08 mg kg⁻¹. The iron content of subsurface varied from 13.06 mg kg⁻¹ in control to 19.94 mg kg⁻¹ in T₁₅.

4.10.2.11 DTPA extractable manganese (mg kg⁻¹)

The nitrogen, phosphorus and potassium levels and ratios had significant effect on DTPA manganese content of soil (Table 4.50 and 4.51). Pooled analysis of two years (2013 and 2014) data of surface soils revealed that the treatment receiving NPK in the ratio 2.4:1:1.2 (150:62.5:75) recorded the highest available manganese content (14.57 mg kg⁻¹). Whereas, the lowest manganese content (9.37) was recorded in control and in all other NPK fertilizer ratios, it ranged from 12.41 to 14.49 mg kg⁻¹. The manganese content of soil was higher in the subsurface layer compared to surface horizon and it ranged from 12.56 in control to 17.81 in T₅.

4.10.2.12 Available boron (mg kg⁻¹)

Pooled analysis of two years data revealed that the available boron content varied significantly due to different levels and ratios of N, P and K fertilizers (Table 4.50 and 4.51). Among the different treatments, the treatment receiving NPK in the ratio 2.0:1:1.5 (T₄) recorded highest available boron content (0.43 mg kg⁻¹), whereas, the lowest content was recorded in control (0.27 mg kg⁻¹). However, it ranged from 0.32 to 0.42 mg kg⁻¹. The boron content of soil has increased compared to initial value and was lower compared to surface horizon and it varied from 0.27 mg kg⁻¹ in control to 0.38 mg kg⁻¹ in T₁₅.

Table 4.50: Effect of NPK levels and ratios on DTPA extractable iron, manganese and available boron (mg kg⁻¹) content of soil (0-15 cm) after the harvest of rice crop grown in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K	Iron			Manganese			Boron		
	kg ha ⁻¹			ratio	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	23.44	21.91	22.68	12.05	13.25	12.65	0.55	0.25	0.40
T ₂	100	37.5	75	2.7:1:2.0	23.05	24.14	23.60	13.63	12.29	12.96	0.57	0.24	0.40
T ₃	100	50	50	2.0:1:1.0	25.83	25.52	25.68	12.25	13.84	13.05	0.50	0.27	0.39
T ₄	100	50	75	2.0:1:1.5	24.96	24.87	24.92	14.47	13.61	14.04	0.55	0.32	0.43
T ₅	100	62.5	50	1.6:1:0.8	22.35	25.49	23.92	13.25	13.09	13.17	0.49	0.23	0.36
T ₆	100	62.5	75	1.6:1:1.2	23.28	28.01	25.65	13.01	12.46	12.74	0.54	0.23	0.39
T ₇	125	37.5	50	3.3:1:1.3	21.97	26.35	24.16	11.42	14.30	12.86	0.51	0.22	0.37
T ₈	125	37.5	75	3.3:1:2.0	22.79	25.32	24.06	12.21	12.79	12.50	0.56	0.24	0.40
T ₉	125	50	50	2.5:1:1.0	24.64	27.51	26.08	12.48	13.26	12.87	0.50	0.24	0.37
T ₁₀	125	50	75	2.5:1:1.5	23.64	27.27	25.46	14.75	14.22	14.49	0.54	0.21	0.38
T ₁₁	125	62.5	50	2.0:1:0.8	25.34	24.10	24.72	13.88	13.11	13.50	0.54	0.30	0.42
T ₁₂	125	62.5	75	2.0:1:1.2	24.20	27.10	25.65	13.47	14.04	13.75	0.47	0.24	0.35
T ₁₃	150	37.5	50	4.0:1:1.3	24.98	27.28	26.13	12.98	14.92	13.95	0.43	0.20	0.32
T ₁₄	150	37.5	75	4.0:1:2.0	25.37	24.42	24.90	13.64	13.88	13.76	0.43	0.20	0.32
T ₁₅	150	50	50	3.0:1:1.0	21.75	27.33	24.54	14.16	12.64	13.40	0.46	0.27	0.37
T ₁₆	150	50	75	3.0:1:1.5	22.39	26.55	24.47	12.63	12.18	12.41	0.52	0.25	0.39
T ₁₇	150	62.5	50	2.4:1:0.8	22.67	25.95	24.31	12.93	13.68	13.30	0.46	0.24	0.35
T ₁₈	150	62.5	75	2.4:1:1.2	23.56	26.76	25.16	14.34	14.79	14.57	0.56	0.26	0.41
T ₁₉	0	0	0	0:0:0	17.80	17.47	17.63	9.27	9.47	9.37	0.37	0.17	0.27
S. Em±					0.65	0.61	0.45	0.51	0.50	0.36	0.03	0.02	0.02
C. D. at 5%					1.87	1.74	1.26	1.45	1.44	1.01	0.09	0.06	0.05

Table 4.51: Effect of NPK levels and ratios on DTPA extractable iron, manganese and available boron (mg kg⁻¹) content of soil (15-30 cm) after the harvest of rice crop grown in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K ratio	Iron			Manganese			Boron		
	kg ha ⁻¹				2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	17.35	19.05	18.20	15.84	17.41	16.62	0.46	0.23	0.35
T ₂	100	37.5	75	2.7:1:2.0	13.97	16.30	15.14	14.68	16.10	15.39	0.39	0.28	0.34
T ₃	100	50	50	2.0:1:1.0	19.66	15.96	17.81	15.43	16.64	16.03	0.40	0.25	0.32
T ₄	100	50	75	2.0:1:1.5	19.26	16.31	17.79	15.76	16.88	16.32	0.43	0.25	0.34
T ₅	100	62.5	50	1.6:1:0.8	16.19	19.55	17.87	17.53	18.10	17.81	0.44	0.23	0.34
T ₆	100	62.5	75	1.6:1:1.2	17.07	16.29	16.68	14.55	14.27	14.41	0.46	0.24	0.35
T ₇	125	37.5	50	3.3:1:1.3	17.11	18.22	17.67	16.16	16.62	16.39	0.43	0.22	0.33
T ₈	125	37.5	75	3.3:1:2.0	18.73	19.26	18.99	16.03	16.82	16.42	0.36	0.24	0.30
T ₉	125	50	50	2.5:1:1.0	16.94	20.59	18.76	13.89	15.48	14.69	0.38	0.30	0.34
T ₁₀	125	50	75	2.5:1:1.5	17.08	18.91	17.99	14.37	16.68	15.53	0.35	0.23	0.29
T ₁₁	125	62.5	50	2.0:1:0.8	16.39	17.61	17.00	15.98	17.83	16.90	0.43	0.29	0.36
T ₁₂	125	62.5	75	2.0:1:1.2	17.68	19.41	18.55	17.56	17.11	17.34	0.35	0.30	0.33
T ₁₃	150	37.5	50	4.0:1:1.3	18.35	16.30	17.32	15.47	18.57	17.02	0.45	0.27	0.36
T ₁₄	150	37.5	75	4.0:1:2.0	18.61	19.73	19.17	14.32	18.68	16.50	0.48	0.22	0.35
T ₁₅	150	50	50	3.0:1:1.0	19.03	20.85	19.94	15.81	18.06	16.93	0.48	0.27	0.38
T ₁₆	150	50	75	3.0:1:1.5	16.04	20.21	18.13	13.17	15.50	14.34	0.48	0.25	0.36
T ₁₇	150	62.5	50	2.4:1:0.8	16.70	19.67	18.18	14.69	18.11	16.40	0.50	0.25	0.38
T ₁₈	150	62.5	75	2.4:1:1.2	15.68	20.07	17.87	17.07	16.81	16.94	0.44	0.29	0.36
T ₁₉	0	0	0	0:0:0	13.77	12.35	13.06	11.78	13.35	12.56	0.32	0.22	0.27
S. Em±					1.74	1.79	1.25	1.09	1.06	0.76	0.05	0.06	0.04
C. D. at 5%					4.98	5.14	3.52	3.14	3.04	2.15	NS	NS	NS

4.10.2.13 Exchangeable Sodium Percentage (ESP) of surface and subsurface soil after the harvest of rice crop during *Kharif* 2013 and summer 2014.

Application of gypsum and NPK at different levels and ratios with farmyard manure significantly decreased the exchangeable sodium percentage of surface soil compared to initial value of 31.8 per cent during 2013 and 2014 (Table 4.52). On the other hand ESP of subsurface has increased in 2013 and a small decrease was observed in 2014 compared to 2013. The ESP of subsurface soil has increased over the initial value of 20.5 per cent

Application of gypsum and nutrients significantly decreased the ESP and it varied between 12.2 (T₁₉) to 17.2 (T₁₈) per cent in 2013 and 12.0 (T₄) to 18.8 (T₃) in 2014. Pooled analysis of two season data revealed that application of gypsum and nutrients significantly decreased the ESP from 31.8 (initial) to lowest (12.4) and it varied between 12.4 (T₁₉) to 16.4 (T₁₈). On the other hand in subsurface soil (15-30 cm depth) it increased over the initial value of 20.5. The exchangeable sodium percentage of subsurface varied from 17.9 (T₂) to 29.4 after harvest of first crop and then it further decreased at harvest of second crop. The ESP of subsurface soil after the harvest of second crop varied from 15.6 (T₄) to 23.0 (T₃). Among the gypsum applied treatments, maximum reduction in exchangeable sodium percentage (16.9 per cent) was recorded in T₁₉ receiving gypsum and FYM.

4.11 Economic analysis

The economic analysis of different treatments receiving NPK fertilizers in different levels and ratios indicated that maximum gross monetary returns and net monetary returns were obtained with the treatment T₁₂ and T₁₅ during the years 2013 and 2014, respectively (Table 4.53). The mean of two years (2013 and 2014) data revealed that maximum gross monetary returns and net monetary returns (Rs. 73,955 ha⁻¹ and Rs. 34,229 ha⁻¹) were obtained with the treatment T₁₅ receiving NPK ratio of 3:1:1 (150 kg N, 50 kg P₂O₅ and 50 kg K₂O ha⁻¹) compared to all other treatments (Rs. 60229 ha⁻¹ to Rs. 73933 ha⁻¹ and Rs. 21,212 ha⁻¹ to 33,527 ha⁻¹, respectively) and control (Rs. 38,948 ha⁻¹ and Rs. 33,527 ha⁻¹).

Table 4.52: Effect of NPK levels and ratios on exchangeable sodium percentage of soil (0-15 and 15-30 cm) after the harvest of rice crop grown in gypsum amended sodic soil during *Kharif* 2013 and summer 2014.

Treatments	N	P ₂ O ₅	K ₂ O	N:P:K ratio	ESP (0-15 cm)			ESP (15-30 cm)		
	kg ha ⁻¹				2013	2014	Pooled	2013	2014	Pooled
T ₁	100	37.5	50	2.7:1:1.3	15.7	16.0	15.8	24.2	21.6	22.9
T ₂	100	37.5	75	2.7:1:2.0	15.1	13.6	14.3	17.9	15.7	16.8
T ₃	100	50	50	2.0:1:1.0	13.3	18.8	16.1	29.4	23.0	26.2
T ₄	100	50	75	2.0:1:1.5	16.7	12.0	14.4	24.4	15.6	20.0
T ₅	100	62.5	50	1.6:1:0.8	13.4	14.0	13.7	21.9	19.0	20.5
T ₆	100	62.5	75	1.6:1:1.2	14.7	15.1	14.9	24.6	20.9	22.8
T ₇	125	37.5	50	3.3:1:1.3	13.8	15.4	14.6	20.9	20.4	20.7
T ₈	125	37.5	75	3.3:1:2.0	13.6	12.2	12.9	22.8	19.8	21.3
T ₉	125	50	50	2.5:1:1.0	13.1	13.4	13.2	21.4	19.3	20.4
T ₁₀	125	50	75	2.5:1:1.5	13.2	15.2	14.2	23.2	20.1	21.7
T ₁₁	125	62.5	50	2.0:1:0.8	13.4	14.7	14.0	21.9	20.4	21.2
T ₁₂	125	62.5	75	2.0:1:1.2	14.7	14.9	14.8	23.9	18.9	21.4
T ₁₃	150	37.5	50	4.0:1:1.3	13.7	15.8	14.7	23.5	21.2	22.4
T ₁₄	150	37.5	75	4.0:1:2.0	15.3	16.3	15.8	25.0	21.9	23.5
T ₁₅	150	50	50	3.0:1:1.0	14.9	12.6	13.7	21.4	18.2	19.8
T ₁₆	150	50	75	3.0:1:1.5	13.8	12.4	13.1	22.4	15.0	18.7
T ₁₇	150	62.5	50	2.4:1:0.8	13.6	12.2	12.9	22.9	15.0	18.9
T ₁₈	150	62.5	75	2.4:1:1.2	17.2	15.5	16.4	22.2	20.3	21.2
T ₁₉	0	0	0	0:0:0	12.2	12.6	12.4	24.4	19.2	21.8
S. Em±					0.8	0.8	0.6	1.6	1.0	0.9
C. D. at 5%					2.4	2.4	1.7	4.6	2.8	2.7

Table 4.53: Economics (Rs. ha⁻¹) of rice cultivation as influenced by NPK levels and ratios in gypsum amended sodic soil in rice-rice cropping system.

Treatments	Cost of cultivation			Gross returns			Net returns			B:C ratio		
	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled
T₁	39017	39017	39017	54484	65974	60229	15467	26957	21212	1.40	1.69	1.54
T₂	39697	39697	39697	55604	69209	62407	15907	29512	22710	1.40	1.74	1.57
T₃	39097	39097	39097	57072	72072	64572	17975	32975	25475	1.46	1.84	1.65
T₄	39777	39777	39777	57416	73126	65271	17639	33349	25494	1.44	1.84	1.64
T₅	39177	39177	39177	58260	75191	66726	19083	36014	27549	1.49	1.92	1.70
T₆	39857	39857	39857	60010	76276	68143	20153	36419	28286	1.51	1.91	1.71
T₇	39332	39332	39332	58094	78094	68094	18763	38763	28763	1.48	1.99	1.73
T₈	40012	40012	40012	58528	80663	69596	18516	40652	29584	1.46	2.02	1.74
T₉	39412	39412	39412	59507	80894	70200	20095	41482	30788	1.51	2.05	1.78
T₁₀	40092	40092	40092	60405	82003	71204	20313	41911	31112	1.51	2.05	1.78
T₁₁	39492	39492	39492	61460	81099	71279	21968	41607	31788	1.56	2.05	1.80
T₁₂	40172	40172	40172	63738	82714	73226	23566	42542	33054	1.59	2.06	1.82
T₁₃	39646	39646	39646	59905	82920	71412	20259	43273	31766	1.51	2.09	1.80
T₁₄	40326	40326	40326	61198	84373	72786	20872	44047	32459	1.52	2.09	1.80
T₁₅	39726	39726	39726	62543	85368	73955	22816	45641	34229	1.57	2.15	1.86
T₁₆	40406	40406	40406	63464	84402	73933	23058	43996	33527	1.57	2.09	1.83
T₁₇	39806	39806	39806	63053	83064	73058	23247	43257	33252	1.58	2.09	1.84
T₁₈	40486	40486	40486	62938	83556	73247	22452	43070	32761	1.55	2.06	1.81
T₁₉	36158	36158	36158	41468	36427	38948	5310	269	2789	1.15	1.01	1.08

Application of NPK fertilizers increased the B: C ratio over the control. Highest B: C ratio of 1.86 was realized in T₁₂ and 2.15 in T₁₅ during 2013 and 2014. The pooled analysis of two year data revealed that the maximum B:C ratio (1.86) was realized in the treatment T₁₅ receiving NPK fertilizer ratio of 3:1:1 (150 kg N, 50 kg P₂O₅ and 50 kg K₂O ha⁻¹) among the different fertilizer ratio and lowest B:C ratio was recorded in the control (1.08).

The B: C ratio in general may be low but the improvement in soil properties/soil health is considered. The B:C ratio may further improve in the coming seasons by yield improvement.

V. DISCUSSION

Results of the investigation on the characterization of salt affected soils in Cauvery Command Area (CCA) and response of rice to different ratios and levels of nutrients in gypsum amended sodic soil are discussed in this chapter. The discussion of the results obtained has been made under the following headings.

I. Characterization of salt affected soils

- 5.1 Physical characteristics of selected profile soil samples
- 5.2 Chemical properties of surface, subsurface and profile soil samples
- 5.3 Nutrient status of surface, subsurface and profile soil samples
- 5.4 Classification of salt affected soils

II. Field experiments

- 5.5 Effect of levels and ratios of NPK on growth and yield of paddy
- 5.6 Effect of NPK levels and ratios on nutrient uptake by paddy
- 5.7 Effect of NPK levels and ratios on nutrient use efficiency
- 5.8 Effect of NPK levels and ratios on soil properties
- 5.9 Effect of different levels and ratios of NPK and gypsum application on economics of rice production

5.1 Physical characteristics of selected profile soil samples

5.1.1 Particle-size distribution

The particle-size distribution constituting the solid phase of soil gives an insight into its physical, chemical and biological potential which vitally contribute to soil management for plant growth through water retention and its availability, effective aeration, nutrition supply and amelioration of problematic soil. For example the gypsum requirement of sodic soil is controlled by clay content of the soil.

The samples collected were fractioned into three size fractions viz. sand, silt and clay (Tables 4.8 to 4.11 and Figure 4). In general the sand, silt and clay particles

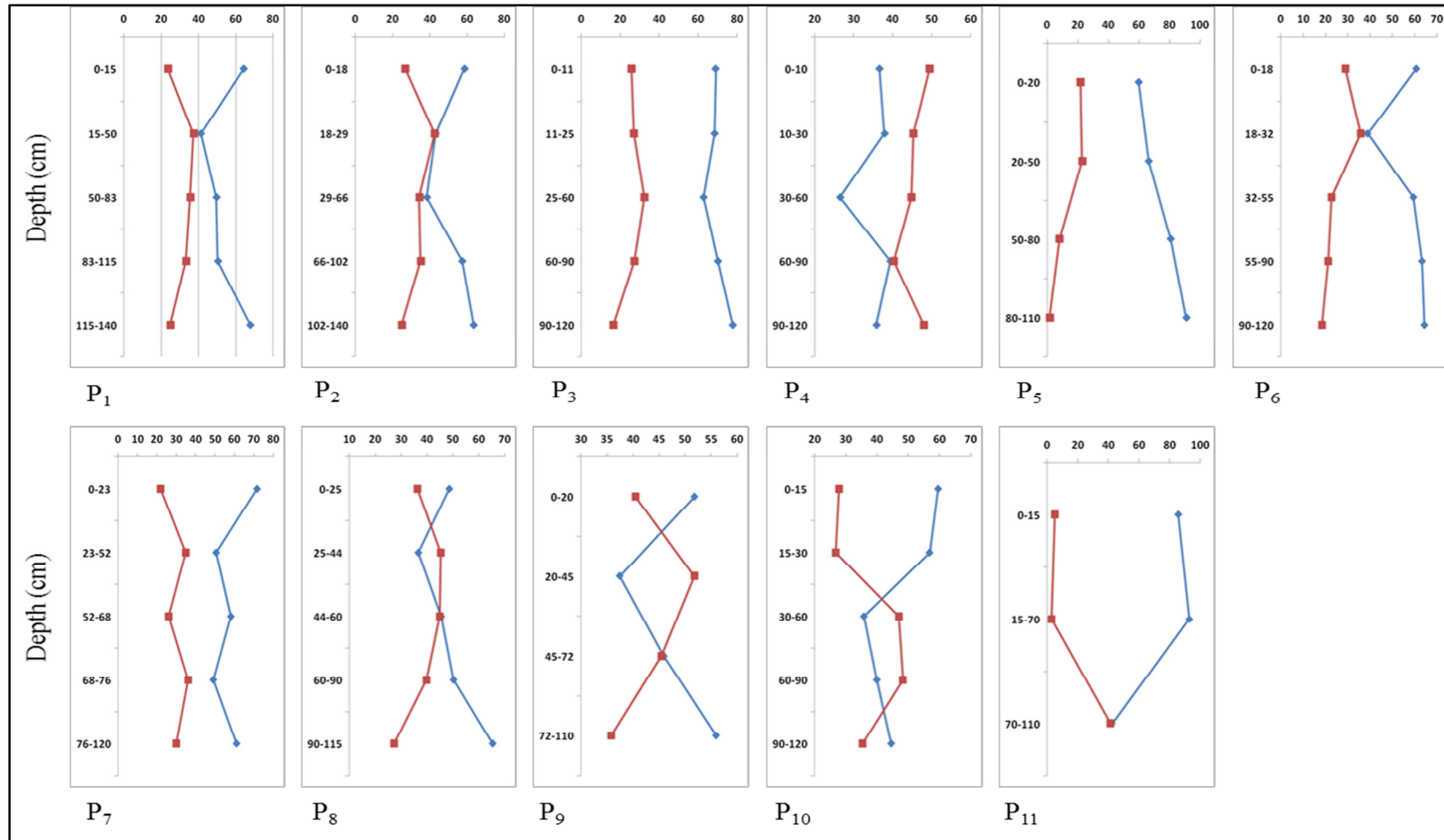


Fig. 4: Depth wise variation in sand and clay percentage in different profiles.

were irregularly distributed in most of the profiles. The variation in clay content ranged from 5.0 to 49.5 per cent in the surface horizons, while in subsurface horizons it varied from 1.5 to 51.8 per cent. Clay content in general was higher in the second depth and then decreased gradually with depth in the profiles P₁, P₂, P₆, P₈ and P₉. This may be because of disintegration of soil aggregates due to cultural practices during dry period and puddling during wet season. The disintegrated particles, especially the finer ones moved downwards through percolating water and deposited in the subsurface horizon. Similar pattern of variation in the clay content with depth was also observed by Puranik *et al.* (1972) and Nimbalkar (1990) in the black cotton soils of Maharashtra and Sharma *et al.* (2004a) in salt affected soils of Rajasthan. The migration of finer particles from surface to subsurface layer and loss of finer particles by erosion may be responsible for the lower clay content in the surface horizons of the profiles (Wischmeier *et al.*, 1971). Consequently higher clay content was observed in the profiles (P₂, P₄, P₇, P₉ and P₁₀) situated in the lower region as compared to higher region and the clay content decreased with the depth in all the profiles. Whereas at site 4 the P₁₁ which is situated very close to natural nala had very low clay content than any other profiles in the study area as it is subjected to frequent flooding. This fact is evidenced in unusually high sand content in this profile (42.4 to 93.0 per cent). Maximum accumulation of clay in the subsurface horizons can be attributed to the illuviation process. Similar findings were also reported by Pathak and Patel (1980), Tiwari *et al.* (1983) and Dubey *et al.* (1984).

The silt content in the profiles ranged from 1.8 to 27.8 per cent with subsurface horizons having relatively more than the surface horizons. The sand content varied from 26.5 to 91.0 per cent. Silt content in general exhibited an irregular trend with depth, this irregular distribution of silt might be due to variation in weathering of parent material or in situ formation (Satish Kumar and Naidu, 2012). Sand constituted the bulk of mechanical fractions, which could be attributed to the siliceous nature of granite-gneiss parent material.

The data on the particle size distribution in Tables 4.8 to 4.11 revealed that texture of the soils ranged from sandy clay loam to sandy clay in uplands and midlands and loamy sand to clay was found in low land soils. The practice of cultural operations like frequent ploughing in uplands and irrigation along with puddling in low land paddy growing tracts caused the textural variation observed in the study area

between low land and uplands. Due to this the surface soil tends to become light textured and with increase in depth the fineness also increased. It was reported by many workers that changes in the particle size distribution under irrigated agriculture is brought about by several processes like accumulation of irrigated deposits in the lower depths (Kovda *et al.*, 1973).

In the present investigation some of the processes mentioned above might have operated exclusively in the irrigated areas of the study. It might also be explained further that the effect of percolating water as well as the low salt and high exchangeable sodium content might have contributed to dispersion and migration of finer particles to the underlying layers.

5.1.2 Bulk density and maximum water holding capacity

The bulk density of soil has increased with depth in all the profiles due to low organic matter content and less aggregation. Low bulk density values of surface soils may be due to higher organic matter content. The water holding capacity of soil irregularly distributed in all the profiles due to the illuviation and eluviation's of finer fraction in different horizons (Tables 4.8 to 4.11). Similar observations were made by Harradine and Jenny (1958). The variation in BD could be attributed to distributions of soil particles (silt and clay content) and exchangeable cations (Krishnamurthy, 1993). Increased water holding capacity with depth may be due to increase in clay content (Challa and Gaikwad, 1987). Higher WHC of soil was noticed at lower depth. It may be due to adsorption of more water by finer fractions as reported by Janardhanan Nair *et al.* (1966).

5.1.3 Calcium carbonate

The free calcium carbonate content in majority of profiles has decreased with depth. In P₅ the CaCO₃ was observed only in the surface horizon (Tables 4.12 to 4.15). The reason for the lime accumulation could be the climate, less rainfall favoring accumulation of calcium carbonate and parent material. Richards (1954) reported that owing to low rainfall and limited leaching, the alkaline earth carbonates are usually a constituent of soils of semi-arid and arid regions. The calcium carbonates in most of the profiles indicate the precipitation of calcium as calcium

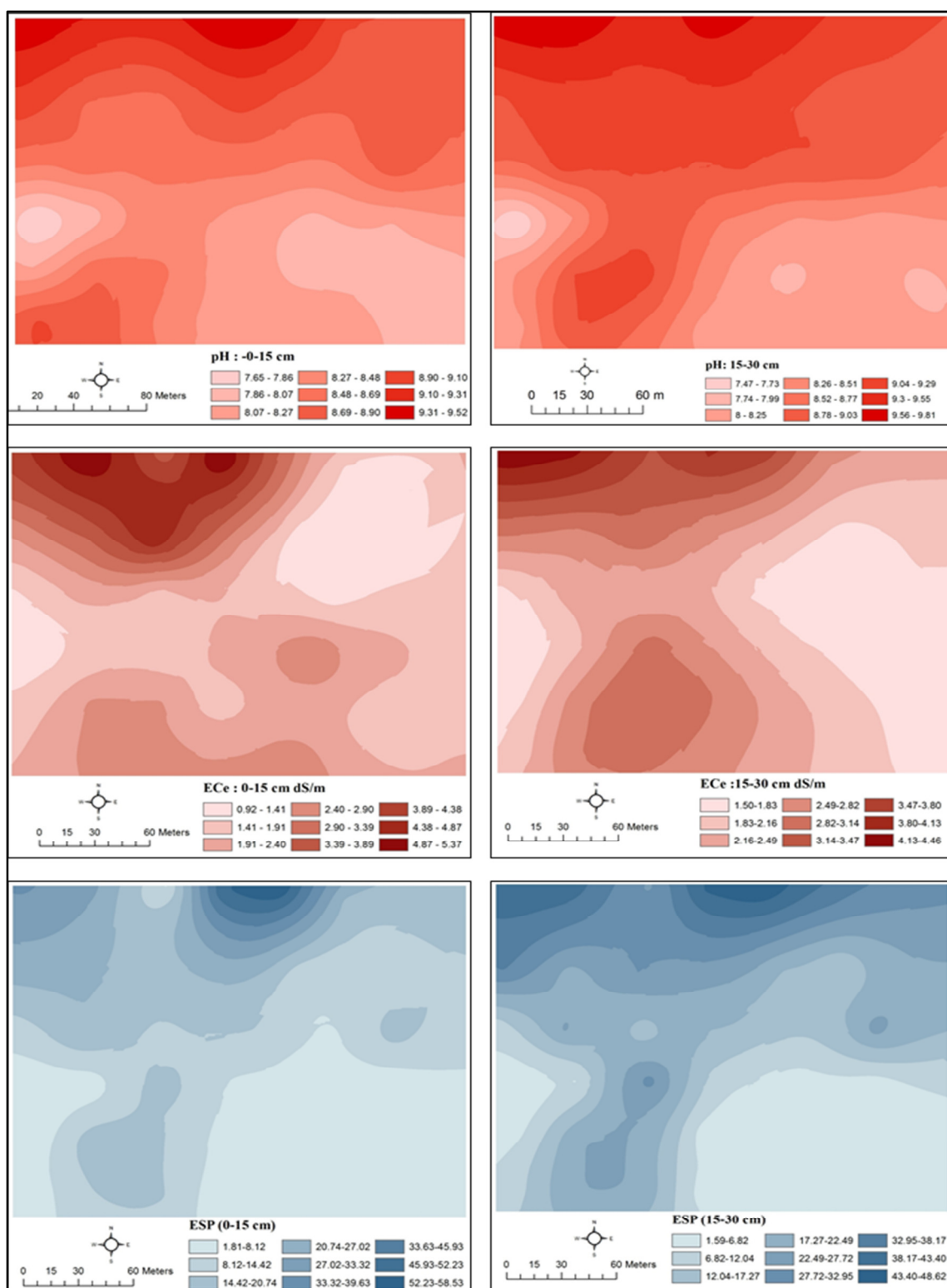


Fig. 5: Map of surface and subsurface soil pH, ECe and ESP of site 1 produced by ordinary krigging.

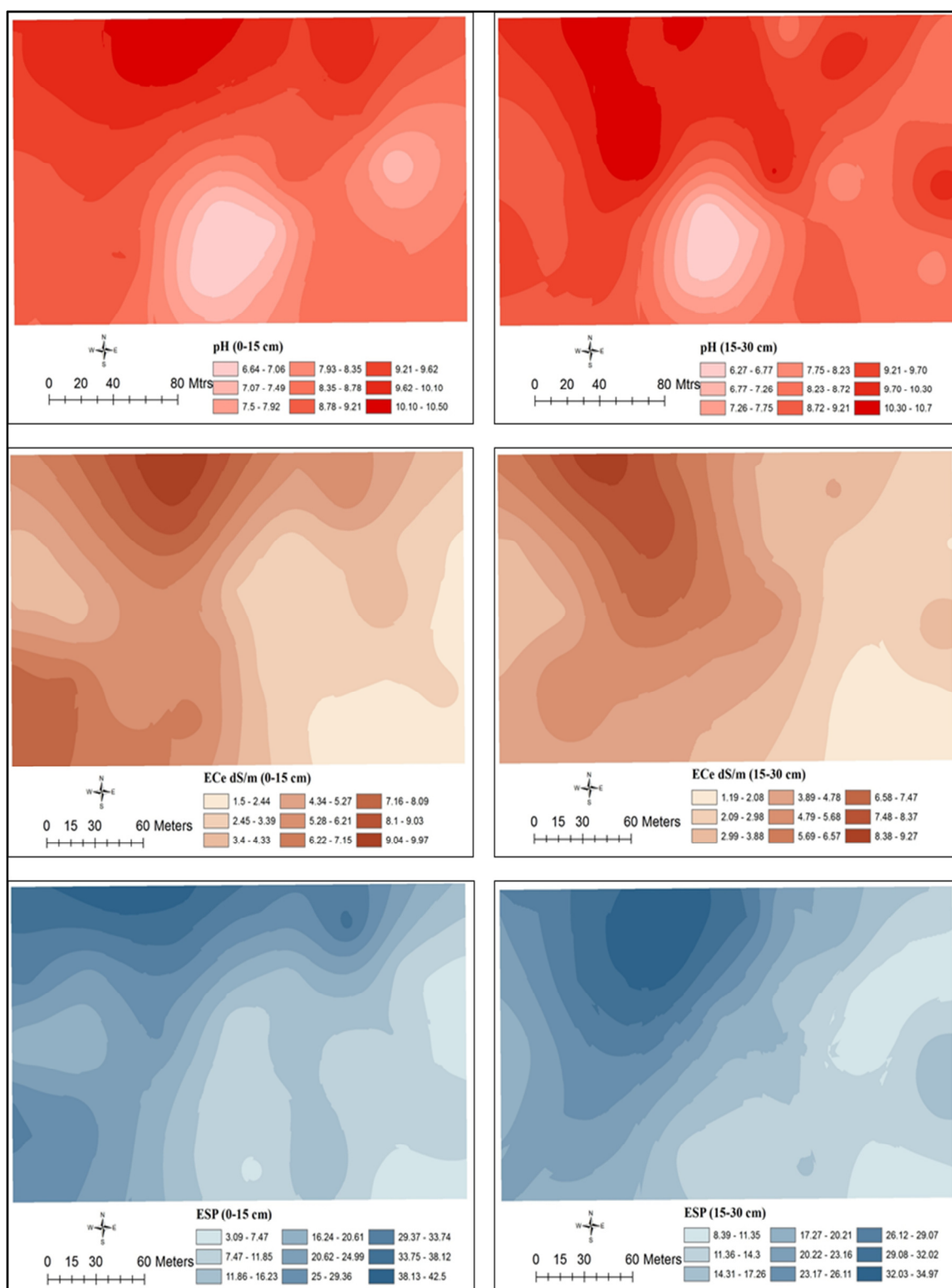


Fig. 6: Map of surface and subsurface soil pH, ECe and ESP of site 2 produced by ordinary krigging.

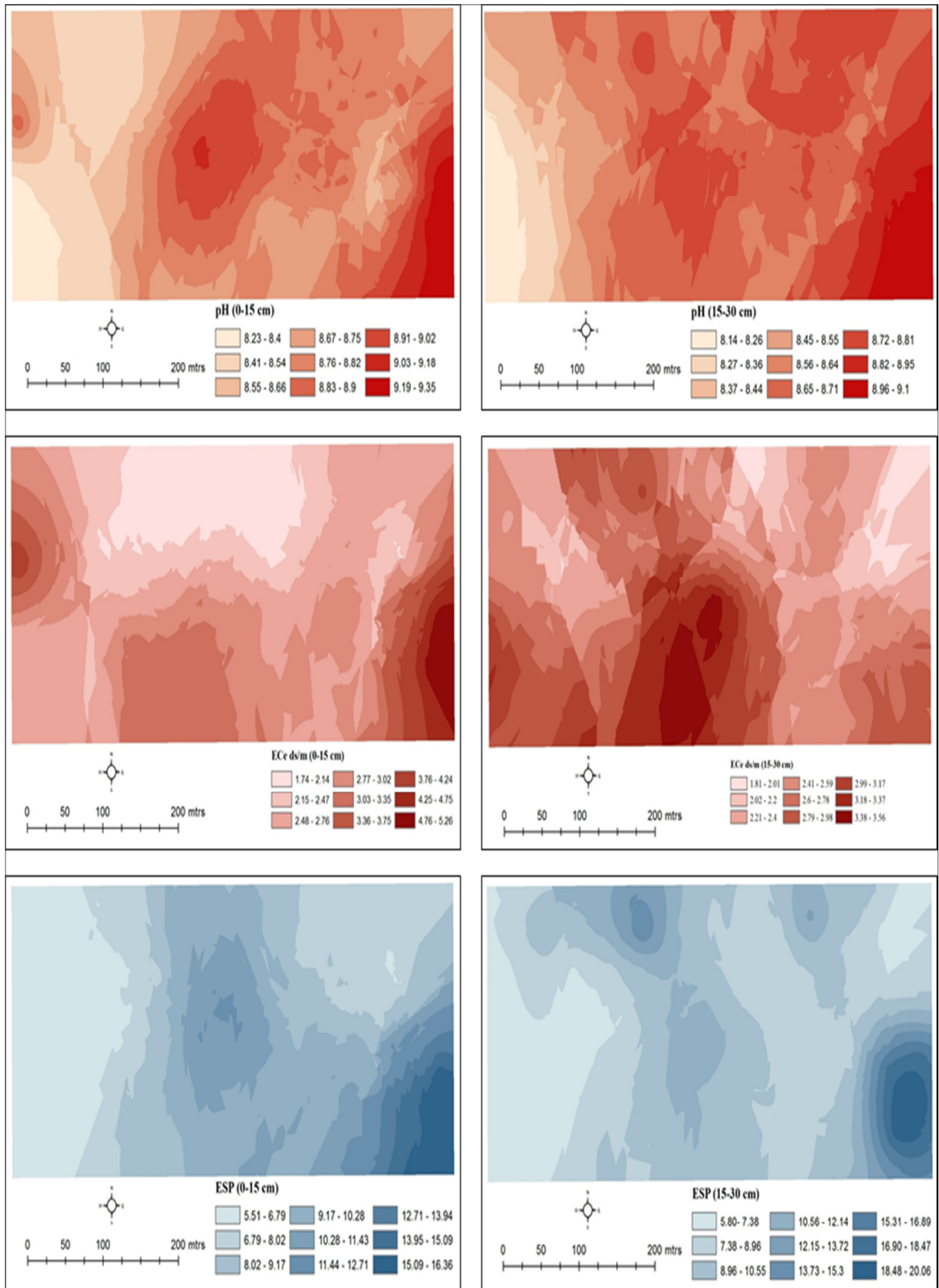


Fig. 7: Map of surface and subsurface soil pH, ECe and ESP of site 3 produced by ordinary krigging.

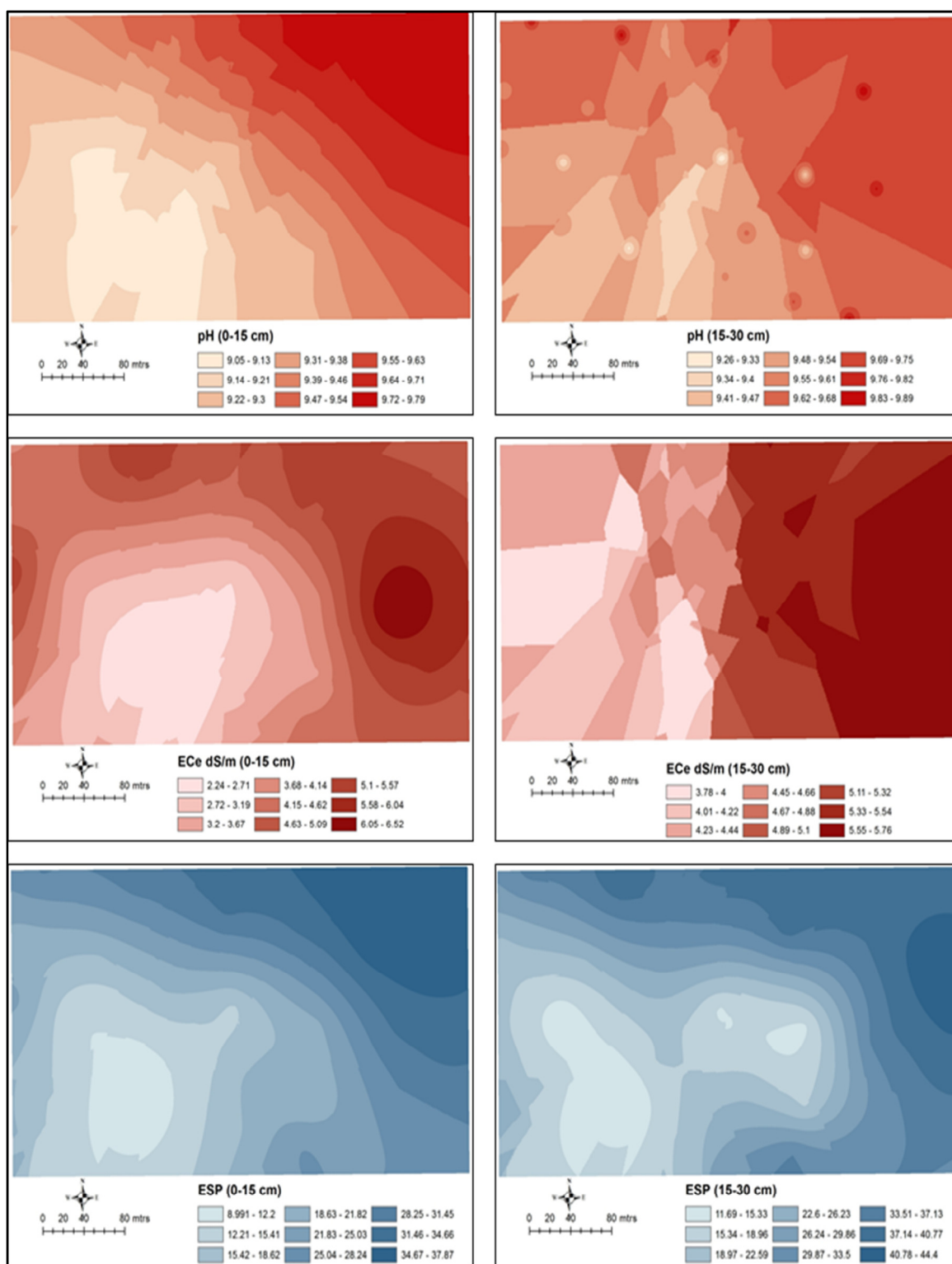


Fig. 8: Map of surface and subsurface soil pH, ECE and ESP of site 4 produced by ordinary krigging.

carbonate because of high pH of 7.5 or above, resulting in the formation of calcium carbonate (Tayim and Al-Yazouri, 2005).

5.2 Chemical properties of surface, subsurface and profile soil samples

5.2.1 Soil pH

The soil samples and profile soil samples of the study area exhibited distinctly alkaline nature with pH values ranging from 6.2 - 10.6 in surface horizons and from 6.2 to 10.7 (Table 4.1) except few samples in some localized spots which recorded slightly acidic reaction. While the profiles P₁, P₂, P₃ and P₈ exhibited increasing trend of pH with depth, other profiles exhibited decreasing trend vertically. Further, it is very interesting note that the pH values of the lowland and midland profiles were slightly higher than uplands. The results are in conformity with those reported by Indra R Singh and Kameriya (2012) in *Natric Troporthents* occurring in semi-arid eco-region of Rajasthan, by Anil Chinchmalatpure *et al.* (2008) in salt affected soils of Samni farm, Bharuch district, Gujarat, Mali *et al.* (2012) in salt affected soil from Barhanpur, M.P. and Yerriswamy *et al.* (1997) in salt affected soils of Upper Krishna Command, Karnataka.

The spatial distribution of surface and subsurface soils as evidenced from the spatial distribution maps (Figure 5, 6, 7 and 8) indicate that the soils with extremely alkaline reaction exists in low land and decreases gradually towards upland in site 1, 2 and 4, with uneven distribution pattern in site 3 with higher pH in upland regions.

The pH of soil is a function of nature and concentration of salts in soils and its value would usually indicate the nature of salts present in the soil. Eaton (1950) revealed that the increase in soil pH beyond 8.5 was mainly because of sodiumization of soils. High pH values of these soils are due to the presence of relatively high proportions of soluble sodium bicarbonates and carbonates. This fact was evidenced by the dominance of soluble sodium in the water extract (Table 4.3) in the present investigation. Similar observations were made by Nakayama (1970). He reported that the domination of carbonates and bicarbonates in soil solution increase the pH to > 8.2. Reaction of exchangeable sodium and calcium carbonates under low CO₂ conditions lead to higher concentration of sodium carbonate and consequently high pH which could be the cause for this trend. Similar observations were made by Kotur

(1985) and Yerriswamy (1996) in salt affected soils of Upper Krishna project in Karnataka. Further, at higher ESP values there will be more hydrolysis of Na that leads to increase in hydroxyl (OH^-) ions resulting in distinct alkaline pH. In the present investigation the ESP of soils ranging between 1.1 and 58.6 confirm release of OH^- ions upon hydrolysis. It was further confirmed by positive and significant correlation (0.651**) obtained between ESP and pH (Table 4.6). Similar results have been reported by Kanwar and Sehgal (1962). The increase in pH down the profile (Fig. 9) could be attributed to leaching and accumulation of soluble sodium salts at lower depths. The higher organic matter content in surface horizons, which on decomposition releases several organic acids, might also be responsible for lower pH values in the surface soil (Bhadrapur and Sheshagiri Rao, 1979).

5.2.2 Electrical conductivity of saturation extract

The electrical conductivity of soil extract is an indirect expression of the total salt concentration in the soil, without reference to the nature and composition of the salts. The ECe values in the study area varied between 0.4 - 11.7 dS m^{-1} in surface layer and from 0.7 to 12.6 dS m^{-1} in the subsurface layer (Table 4.1) and generally remained higher in the substratum than in the surface horizons (P_1 , P_3 , P_7 and P_{10}) while in other profiles, higher ECe value was observed in the surface horizons than the subsurface horizon. The vertical distribution was not showing definite trend in most of the profiles (Fig. 10). Perusal of ECe values of the study sites indicate that the soils are most likely to be saline or saline-sodic or sodic. The higher ECe value suggests that salts are being added to these soils during irrigation. The results are in line with those reported by Balpande *et al.* (1996). They attributed higher electrical conductivity in lower depths due to leaching of salts from the upper layers and their accumulation in the lower depths on account of irrigation. The accumulation of soluble salts in higher amount indicates restricted drainage or shallow water table which may be the cause for such accumulation resulting in higher ECe values. Similar range of ECe value was reported by Kewade *et al.* (2005) in the sodic soils (0.17 to 0.80 dS m^{-1}) of Purna Valley, Maharashtra, by Jayakumar *et al.* (2012) in North Western zone of Tamil Nadu (0.2 to 1.2 dS m^{-1}), by Mruthunjaya and Kenchanna Gowda (1993) in Vanivilas command area of Karnataka (1.83 to 3.68 dS m^{-1}) and by Singh *et al.* (2000) in old alluvial soils of Indo-gangetic plain (2 to 9.6 dS m^{-1}).

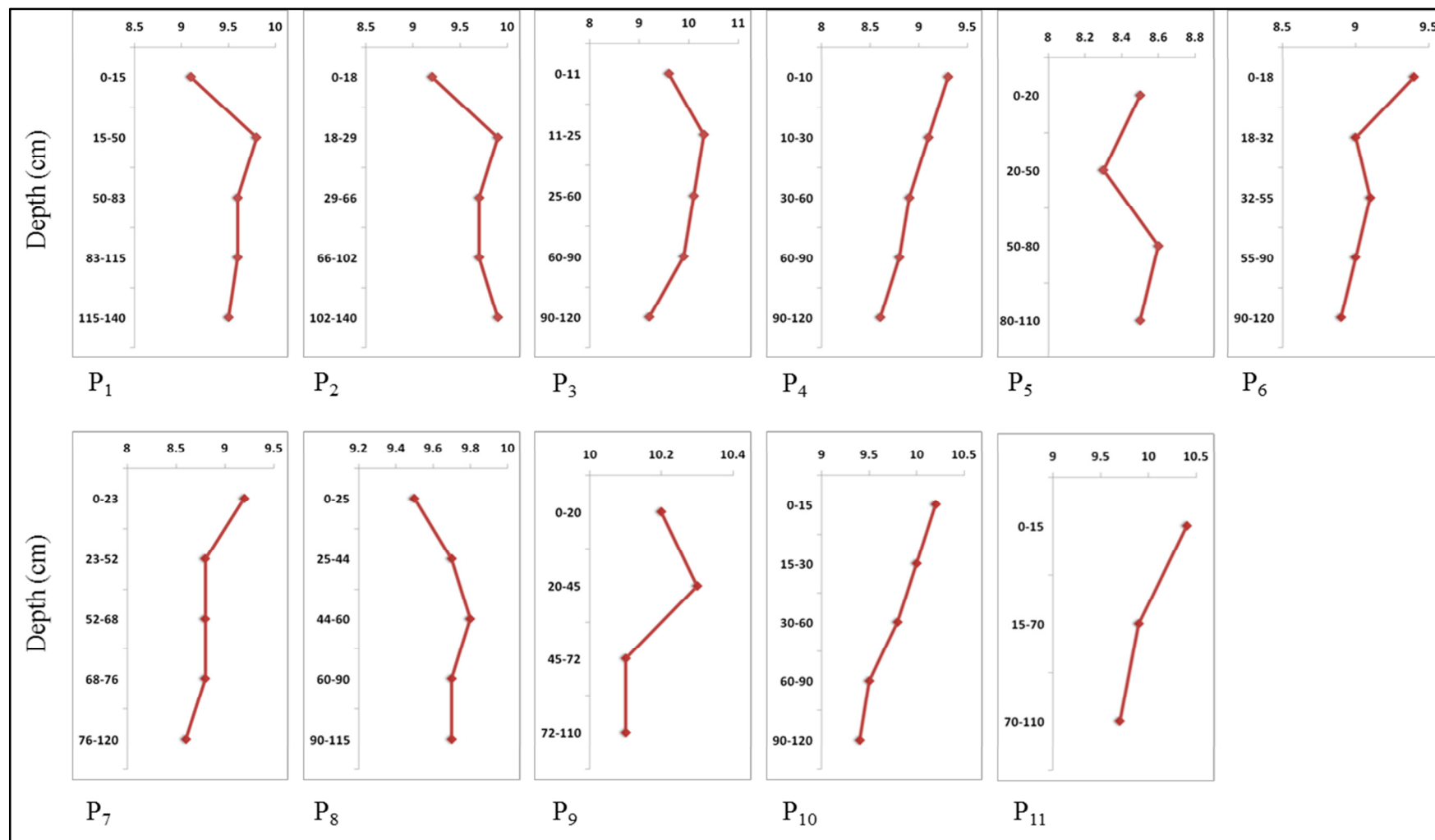


Fig. 9: Depth wise variation in pH value of different profiles.

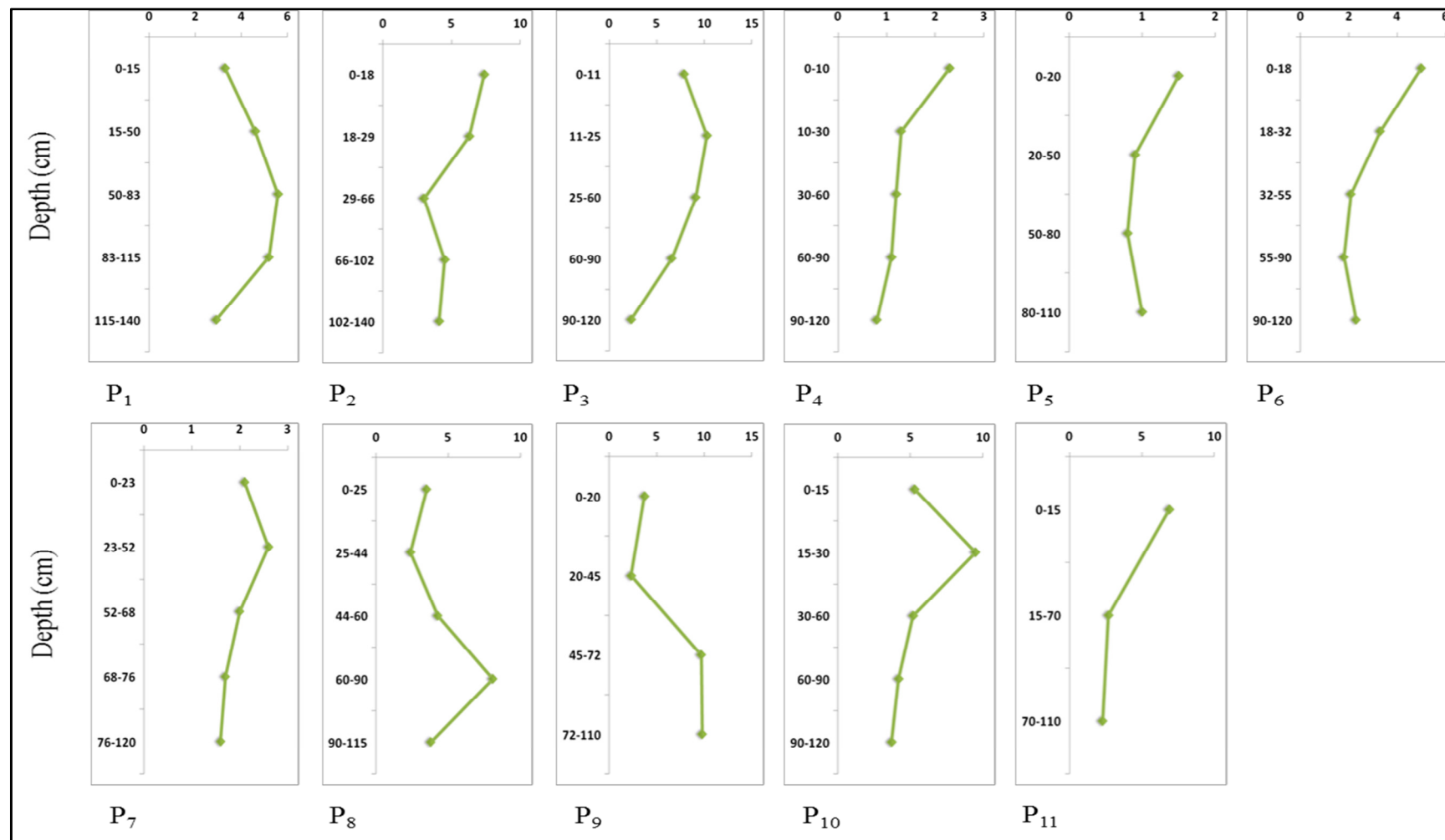


Fig. 10: Depth wise variation in salt content (EC_e - dS m⁻¹) of different profiles.

In all the sites except site three, ECe values were low in higher elevation which may be attributed to leaching of salts to downward region. Similar results were reported by Poonia and Bhumbra (1973) and Sitanggang *et al.* (2006). This was observed in the spatial distribution maps presented in Fig. 5, 6, 7 and 8.

5.2.3 Exchangeable cations

Calcium was the dominant cation followed by magnesium, sodium and potassium on the exchange complex in all the four sites (Table 4.1). The spatial distribution of surface and subsurface soils as evidenced from the spatial distribution maps (Figures 11, 12, 13 and 14) indicate that the soils in the low land form are high in exchangeable sodium and it decreased gradually towards upland except in site 3 where it was irregularly distributed in the study site.

Moderate to strongly alkaline reaction of soils of the study area and an accumulation of salts in the soil resulted in high values of exchangeable Na and Ca followed by Mg and K along the slope gradient. Moreover, medium to fine texture of these soils, their high moisture retentivity for considerable period, relatively poor drainage and semi-arid conditions further contributed to accumulation.

Any increase in alkalinity must be accompanied by an equivalent increase in total cations, carbonate contents and their relationship with pH. Exchangeable sodium per cent of these low land soils clearly indicates the sodiumization of these soils. Although calcium is the dominant cation, the soils of the low lands are still sodiumized because of the inter-relationship among soluble sodium and exchangeable sodium with CEC (Fig. 11, 12, 13 and 14).

Krishnamurthy and Govindarajan (1977) have opined that the fineness of the texture determines the degree of the hazard of the exchangeable sodium per cent in soils. In the profiles, exchangeable sodium content increased with depth (Fig. 15). High sodium content in subsurface layers was due to its greater solubility, leaching and accumulation of sodium salts at lower depths. Similar observation with respect to distribution of sodium was observed by Subbaiah and Manickam (1992).

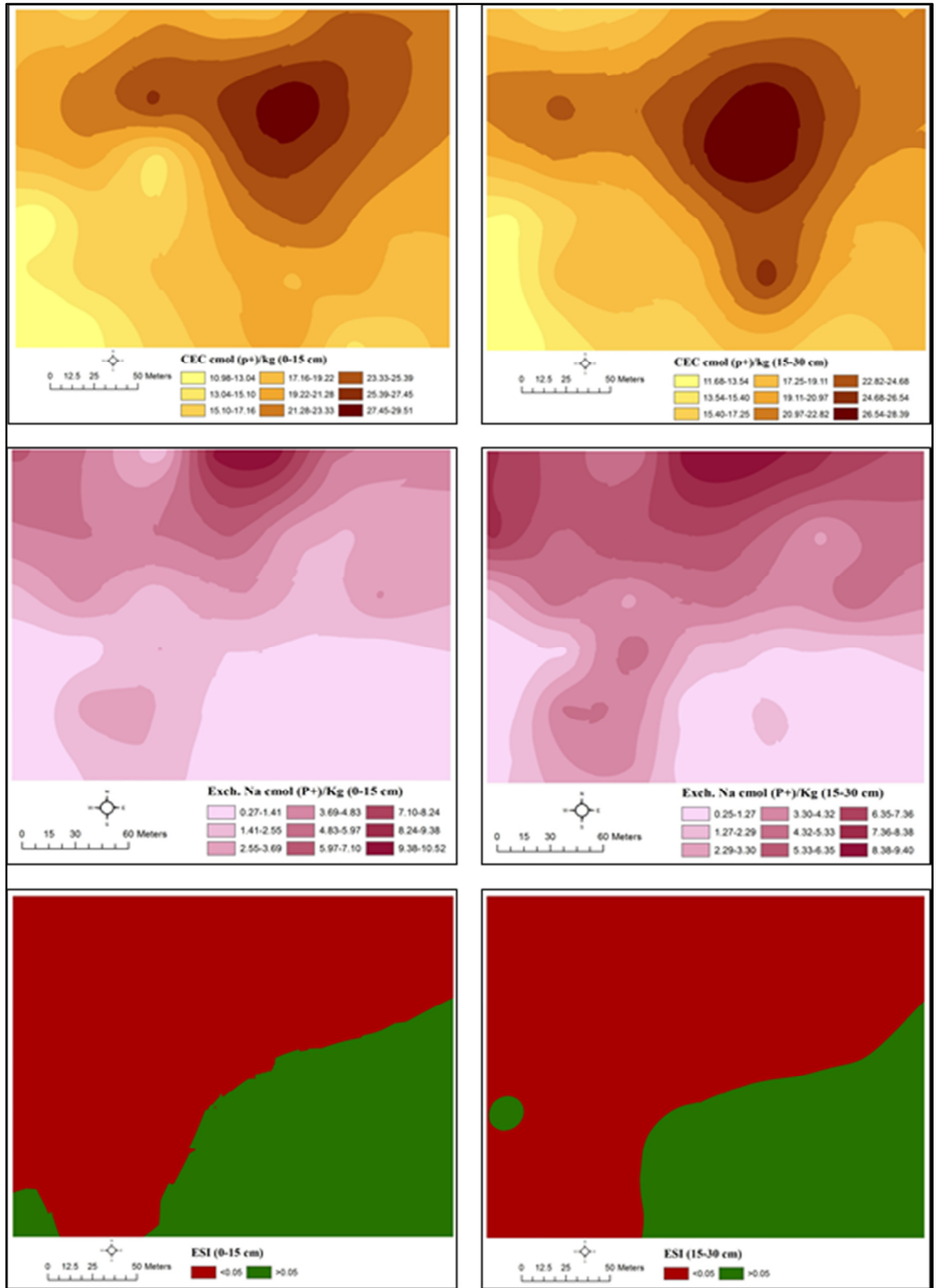


Fig. 11: Map of surface and subsurface soil CEC, exchangeable sodium and ESI of site 1 produced by ordinary krigging.

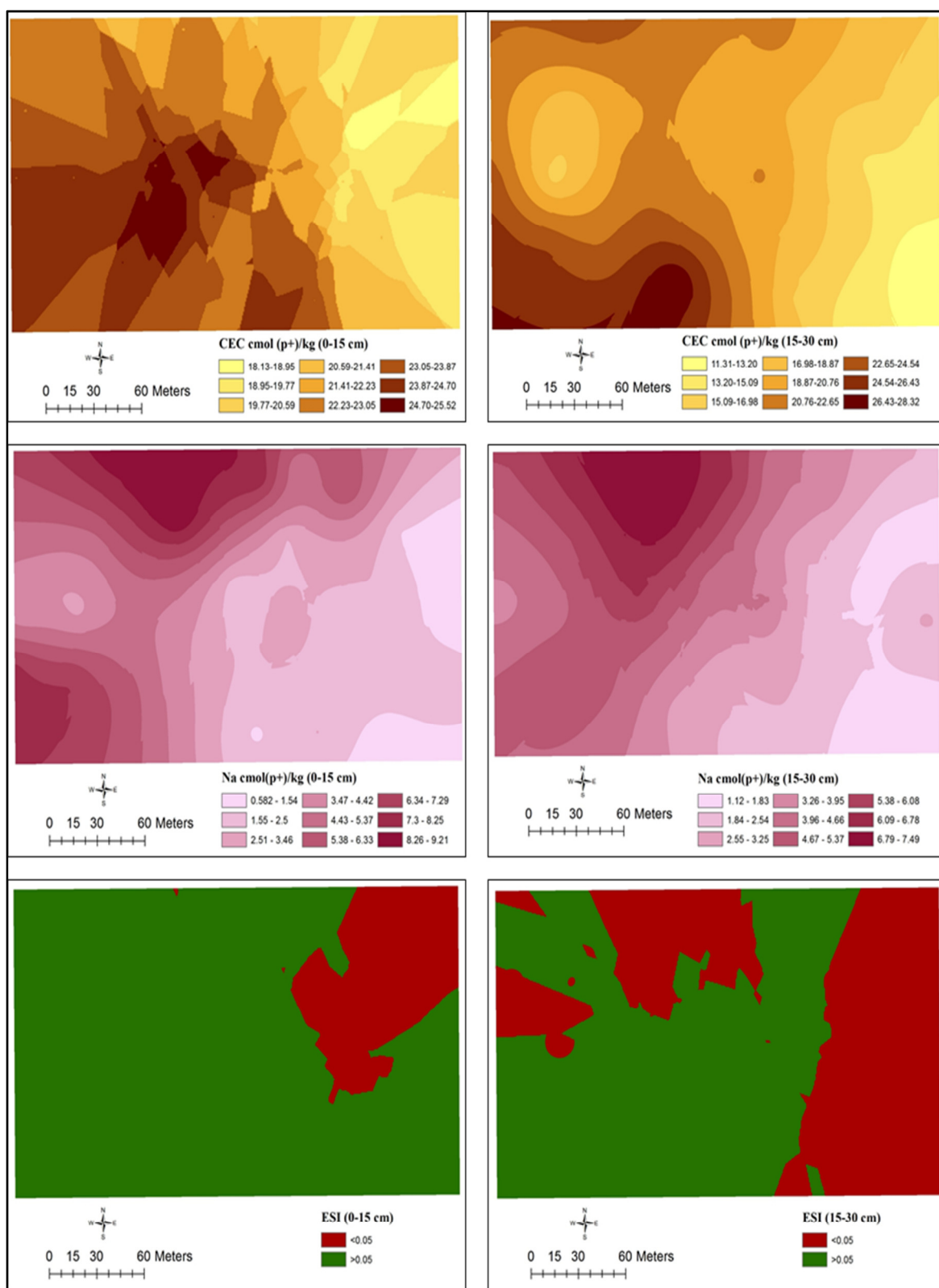


Fig. 12: Map of surface and subsurface soil CEC, exchangeable sodium and ESI of site 2 produced by ordinary krigging.

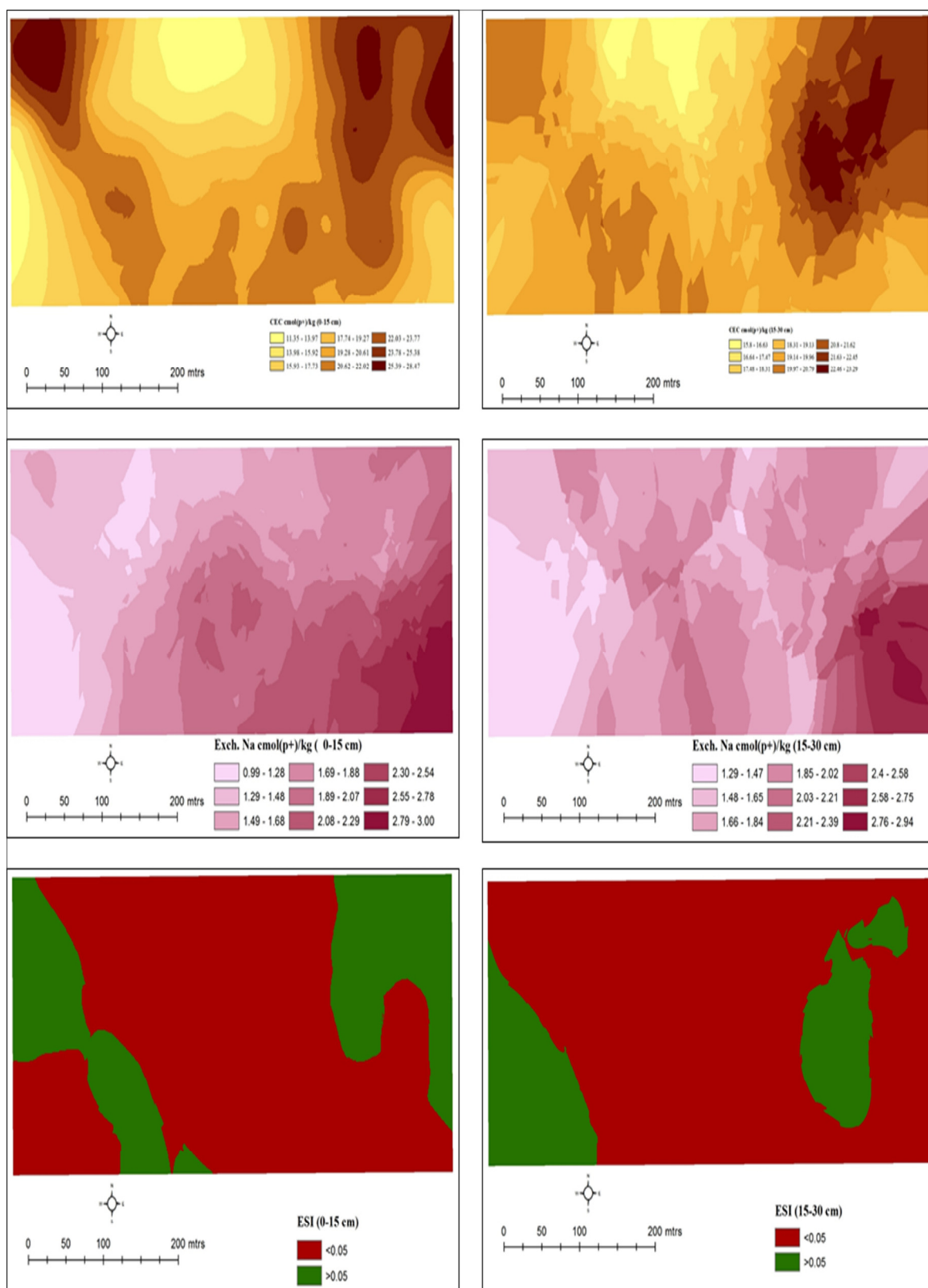


Fig. 13: Map of surface and subsurface soil CEC, exchangeable sodium and ESI of site 3 produced by ordinary krigging.

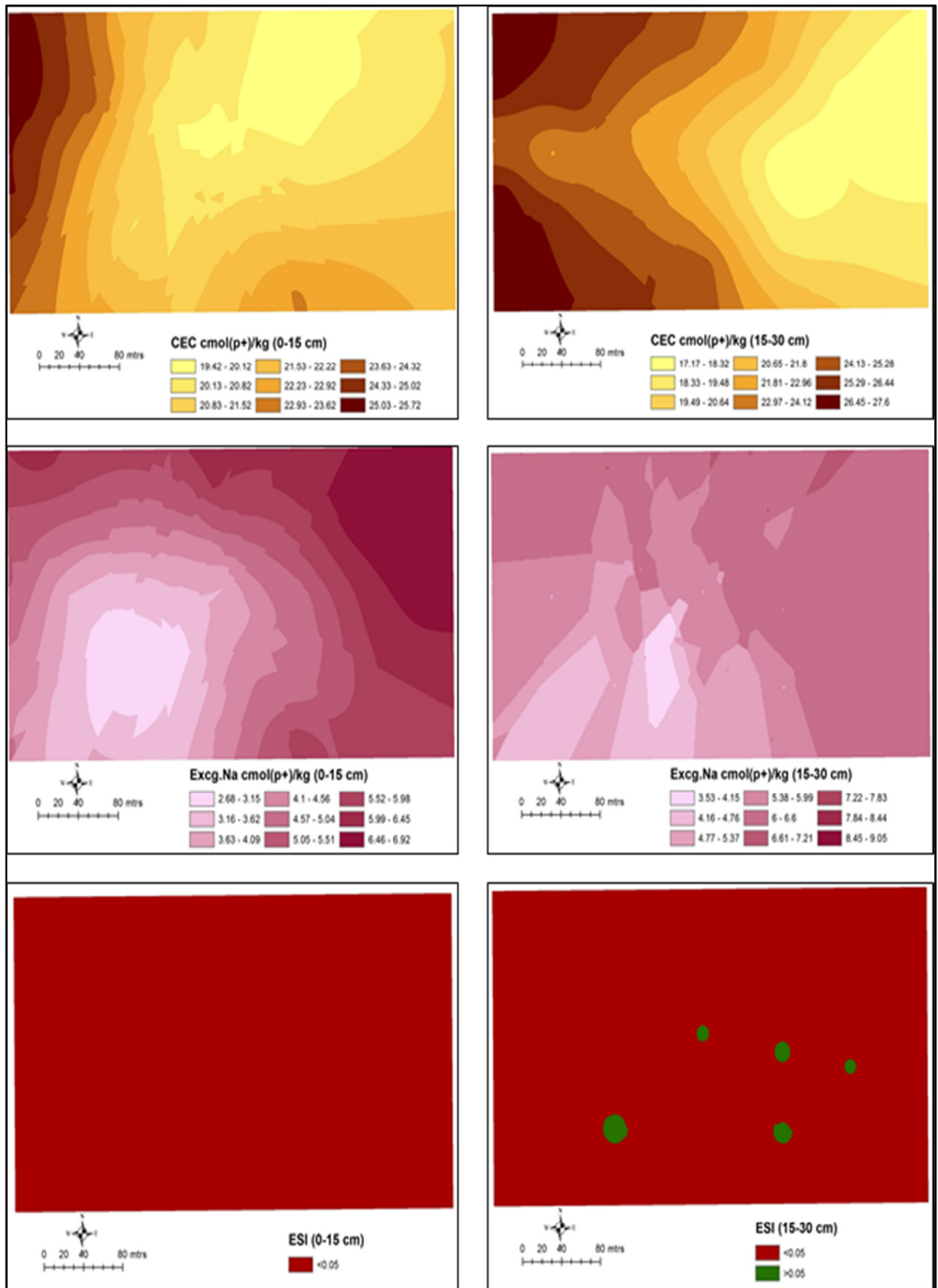


Fig. 14: Map of surface and subsurface soil CEC, exchangeable sodium and ESI of site 4 produced by ordinary krigging.

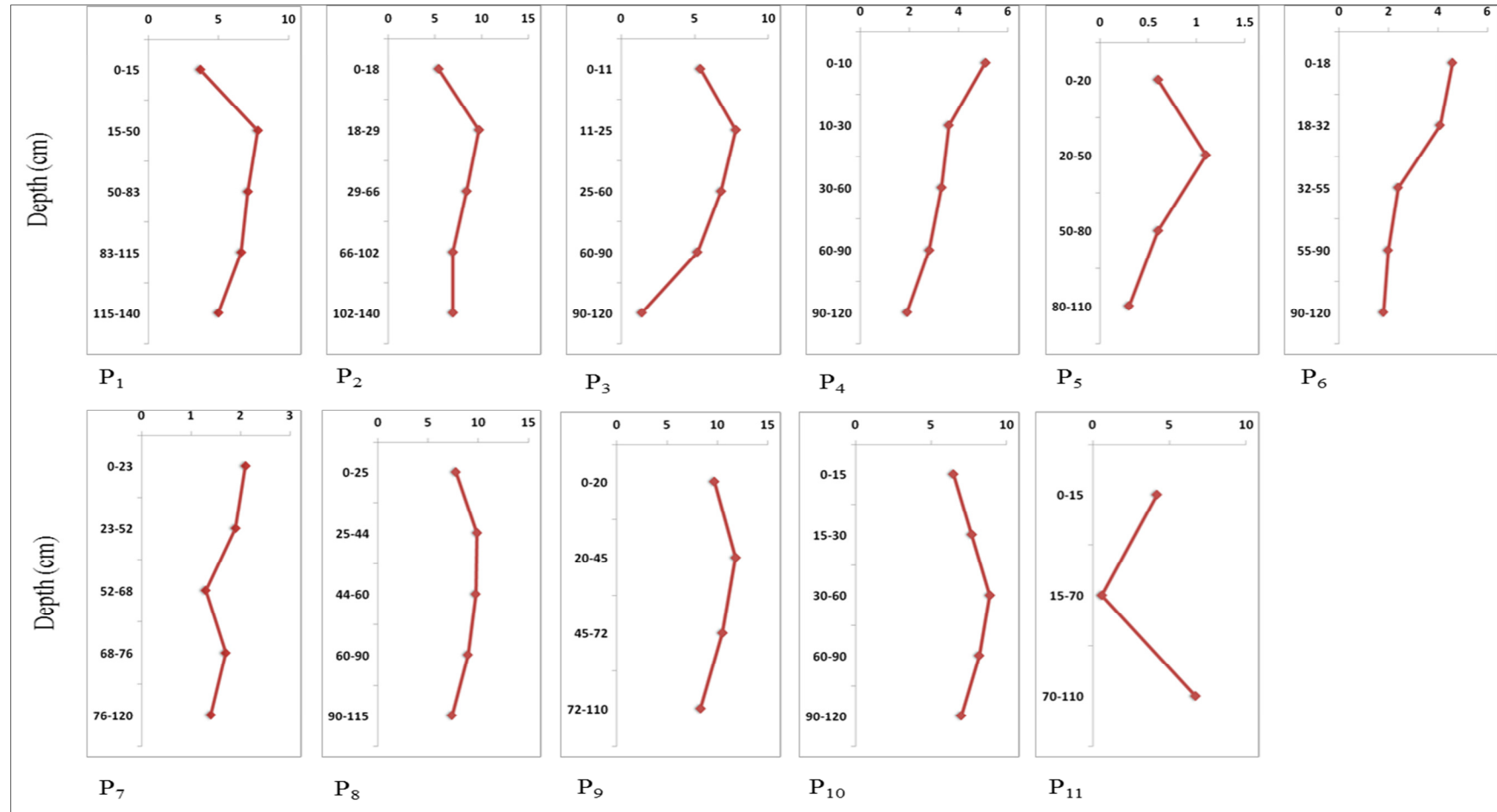


Fig. 15: Depth wise variation in exchangeable Na (cmol [p⁺] kg⁻¹) value in different profiles.

5.2.4 Cation exchange capacity (CEC)

The CEC of surface soils varied from low to high and it ranged from 9.8 to 33.0 $\text{cmol}(\text{p}^+) \text{kg}^{-1}$ soil (Table 4.1). The spatial distribution of CEC as evidenced from the spatial distribution maps (Fig. 11, 12, 13 and 14) indicate that the upland soil have higher CEC compared to lowland soil in all sites except site 3 where higher CEC values were observed in lowland regions.

The CEC in the profile soils was as low as 4.1 to as high as 61.9 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$ soil and higher CEC value was observed in the second layer, which decreased gradually with depth (Fig. 16). The wide variation in CEC of the soils observed in the study area could be ascribed to variation in clay (Table 4.8 to 4.11) and organic matter content (Table 4.12 to 4.15). The higher CEC in the second layer might be attributed to illuvial accumulation of clay and humus. Similar values of CEC with depth in black and associated soils have also been reported by More *et al.* (1988) and Kaswala and Deshpande (1983).

5.2.5 Exchangeable sodium percentage (ESP)

Exchangeable sodium percentage is considered as an important and reliable index for classifying salt affected soils. If the ESP value of soil is less than 15 then soils could be saline or non sodic soils and all other soils having ESP greater than 15 are grouped as sodic or alkali soils according to USDA Handbook No. 60 (Richards, 1954). The ESP is an expression of the sodicity and dispersion tendency of a soil.

The mean ESP of surface soils ranged from 9.1 to 22.7 and from 9.6 to 26.4 in the subsurface samples (Tables 4.2). The ESP less than 15 indicates the absence of alkalinity and sodium hazard (Richards, 1954 and Jackson, 1958).

The data on ESP of profile samples varied from a minimum of 1.8 to a maximum of 46.9 and its value in some profiles was higher in the second layer and then gradually decreased with depth (Fig. 17). This pattern followed the clay distribution pattern (Fig. 4). While in some profiles it gradually decreased with depth. The variation in the vertical distribution of ESP might be attributed to variation in clay and organic matter content and exchangeable cations. $\text{ESP} < 15$ was observed in P₄, P₅, P₆ and P₇ because of low clay and dominance of other cations over Na. Slightly lower ESP at the surface layer in some profiles may be attributed to high organic

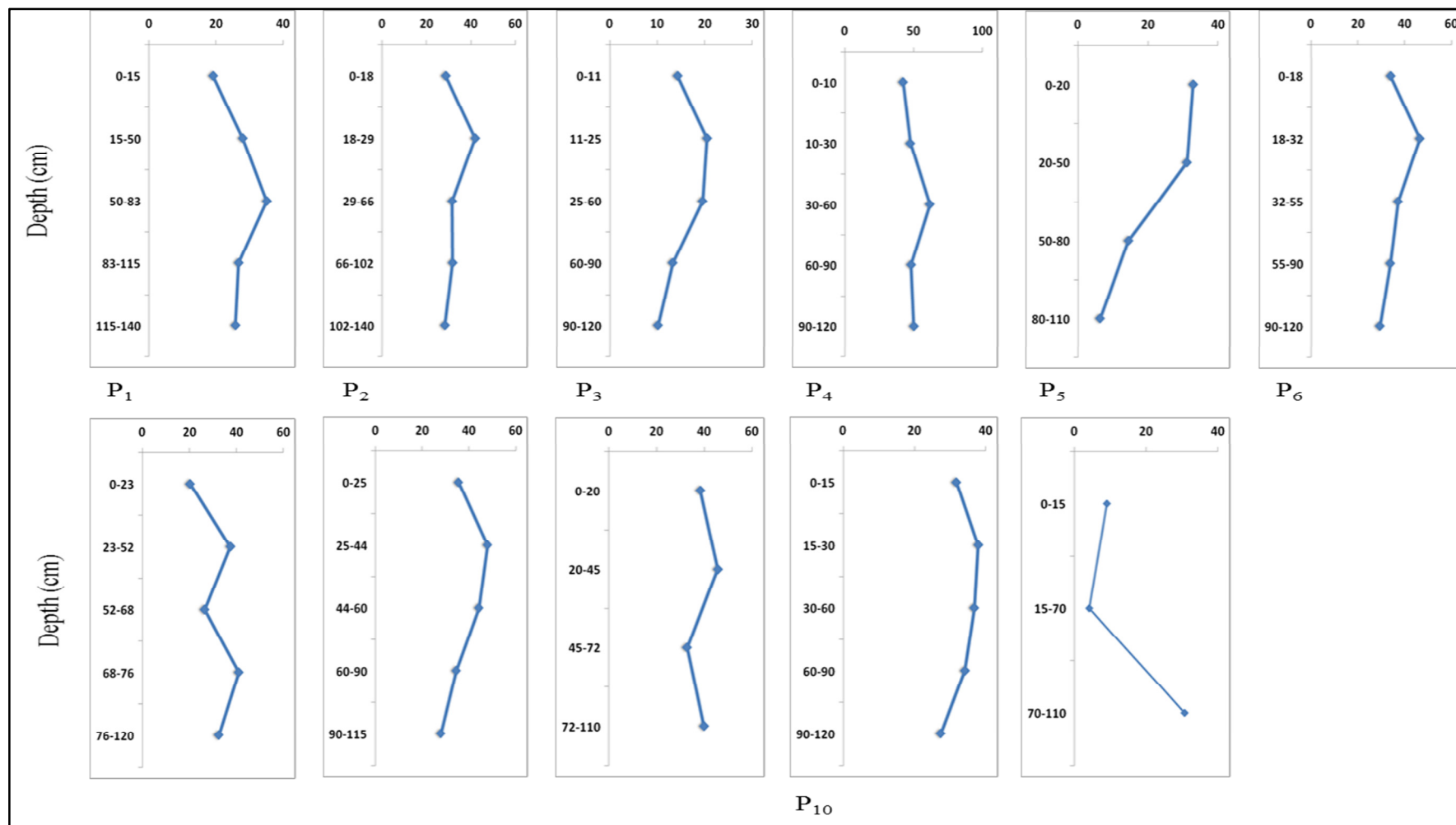


Fig. 16: Depth wise variation in CEC (cmol [p⁺] kg⁻¹) values in different profiles.

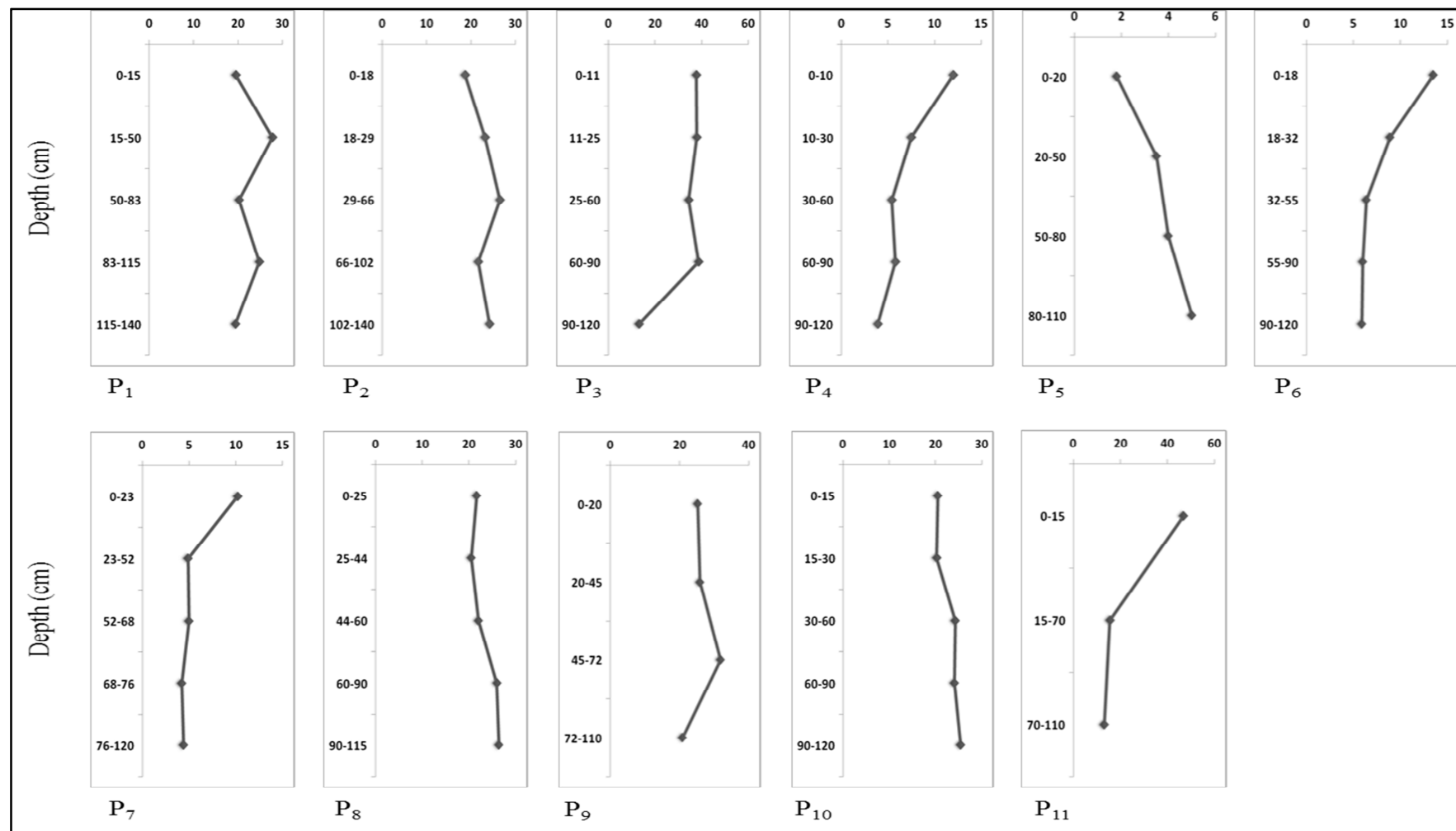


Fig. 17: Depth wise variation in ESP values in different profiles.

carbon content of the soil (Garg and Jain, 1996). The reduction in the ESP is due to evolution of CO₂ released during the decomposition of organic matter. The released CO₂ reacts with water to form carbonic acid which in turn solubilizes the precipitated calcium carbonate. Calcium so released replaces sodium from the exchange complex besides leaching of soluble sodium. This reduces the soil sodicity and pH values in the surface layers. Increase in ESP in the subsurface indicates the movement of displaced Na which later adsorbed on clay complex resulting in higher ESP down the soil depth. Similar observations were made by Yerriswamy (1996) for salt affected soils of Upper Krishna Project in Karnataka and Balpande *et al.* (1996) for Poorna Valley in Maharashtra. On the contrary Tiwari *et al.* (1983) and Sharma *et al.* (1986) have noted sodiumization of surface soils and decreasing trend of ESP with depth in the soil profile of Vertisols of Maharashtra.

The spatial distribution as evidenced from the spatial distribution maps (Fig. 5, 6, 7 and 8) indicate that the higher ESP values were observed in the lower land form and decreases gradually towards upland in sites 1, 2 and 4 but reverse trend was observed for the site 3, where higher ESP values were observed in the higher region. The higher ESP in subsurface soil layer compared to surface soil layer might be attributed to clay content and accumulation of soluble sodium. An increase in ESP down the soil layers has been recorded by Schoonover *et al.* (1957) and Kanwar and Sehgal (1962), Jain and Saxena (1975) and Katti and Rao (1979). According to these authors, the process of initiation of sodification can be ascribed to the effect of fluctuation in water table, movement and accumulation of salts and precipitation of Ca as calcium carbonate.

Bhargava (1979) reported that, alkali soils of South India have high exchangeable sodium percentage values due to high clay content (35 to 40 per cent). Similarly, Krishnamurthy and Govindarajan (1977) reported that the alkali soils of Andhra Pradesh, in spite of dominance of calcium, has exchangeable sodium percentage values of more than 15 and was due to higher clay (28 to 49 per cent) content, makes the soil behave as alkali soils.

5.2.6 Ratios (Ca:Mg and Ca:Na)

The calcium to magnesium and calcium to sodium ratio is a statement of the relative proportion of exchangeable calcium, magnesium and sodium in soil. The

Ca:Mg ratio in surface soil varied from 0.4 to 20.0 in surface and 0.3 to 38.5 in subsurface. The Ca:Na ratio in surface soils varied from 0.4 to 54.4 and in subsurface it varied from 0.5 to 48.7 (Table 4.2).

The mean Ca:Mg and Ca:Na ratios in the surface and subsurface samples of different locations indicate that it was marginally higher in sites 1 and 2 compared to sites 3 and 4. Comparatively narrow Ca:Mg and Ca:Na ratio in the surface soils in sites 3 and 4 as well as in the profile samples (except profiles of site 3 with respect to Ca:Na) might be attributed to the extreme suppression of Ca solubility, substitution of Mg or Ca by plants and recycling of unusual amount of Mg and/or Na. Similar results were reported by Raghuwanshi *et al.* (2011). The magnesium can have a negative effect similar to that of Na on soil physical properties when its concentration is relatively high compared to calcium. The magnesium has a specific effect on soil clay flocculation and surface sealing due to hydration behavior differing from calcium. The hydrated magnesium is hard to dehydrate, its radius is ~400times larger than its dehydrated radius, whereas sodium is ~25 times larger and calcium is ~25 times larger than dehydrated radius.

5.2.7 Electrochemical Stability Index (ESI)

It is well understood that as the EC increases, the potential for the soil to disperse decreases. Hence, Electrochemical Stability Index (ESI) can be used as an indicator for the soil structural stability. McKenzie (1998) used this criterion to know the potential dispersability of soil and stated that the potentially dispersive soil should have an ESI value less than 0.05. ESI values of the soil samples of the study area (both surface and profile samples) was < 0.05 indicating poor soil structure which may result in dispersion of the soil aggregates. The spatial distribution as evidenced from the spatial distribution maps indicate that the soils with ESI value < 0.05 exists in low land and decreases in upland. (Figures 11 to 14). Very low ESI values reveal that the soil is mostly sodic in nature than saline. Many studies have documented the tendency for soil dispersion to increase as salinity declines in the presence of higher amount of exchangeable sodium (Shainberg and Letey, 1984; Summer, 1993; Rengasamy and Summer, 1998). As the soil exchangeable sodium increases it requires higher amount of soluble salts to stabilize the soil. The Lower ESI value of the study area indicate that significant portion of the study area is found highly

degraded soil structure and unstable soil with potentially high soil dispersion. From these results, it is evident that the landform has played a major role in influencing soil physical and chemical properties.

5.2.8 Water soluble ions of surface, subsurface and profile soil samples

5.2.8.1 Soluble cations

The concentration of cations in the studied sites followed the order Na >Ca >Mg >K (Table 4.3). This showed that the water soluble sodium was dominant soluble cation. The predominance of sodium over other cations is mainly due to higher solubility compared to Ca, Mg and K salts. Similar results were obtained by Sunitha (2008), More *et al.* (1988), Ballolli (1987) and Balpande *et al.* (1996). The sodium concentration increases with depth in all the profiles as sodium salts are more mobile and hence accumulate at lower depths (Table 4.16 to 4.19). The water soluble calcium, magnesium and potassium decreased with depth in all the profiles. The potassium content in water extracts appeared to be higher, which could be arising on account of dissolution of potash bearing minerals, such as mica and feldspars in sand and clay fraction of the soil.

5.2.8.2 Soluble anions

Chlorides were the dominant anions, followed by bicarbonates, sulphates and carbonates in all the sites (Table 4.3) and profiles (Table 4.16 to 4.19) throughout the depth. Chloride concentration was found to increase with depth because of its close affinity with sodium and these are more mobile and move to lower depths. The carbonate content varied from traces to 5.23 me L⁻¹ in the samples. Bicarbonate concentration was found to be more in salt affected profiles. Dubey *et al.* (1983) also reported higher bicarbonate content in salt affected Vertisols as well as in normal soil.

5.3 Nutrient status of surface, subsurface and profile soil samples

5.3.1 Soil organic carbon (SOC)

Soil organic matter is the major pool of nutrient elements for plant growth. The organic carbon is an indicator of chemical and biological changes taking place in soil and also plays a major role in mineralization and transformation of nutrients in soil (Hebbara *et al.*, 1992).

Organic carbon status in soils was low to high (3.2 to 8.1 g kg⁻¹) in range (Table 4.4). The high organic carbon status of soils could be attributed to addition of plant residues, FYM and compost to the surface horizons than the lower horizons. The lower organic matter content in the soils might be attributed to the prevalence of tropical conditions, where the degradation of organic matter occurs at a faster rate coupled with low vegetation cover, there by leaving less organic C in the soils. Similar observations were noticed by Nayak *et al.* (2002).

The organic carbon content of profile samples has decreased with depth (Table 4.12 to 4.15). The higher organic carbon content in surface samples and its decrease with depth might be attributed to addition of crop residues or FYM and root decomposition. Another fact is as the soils are sodic in nature which caused the dispersion of clay particles and also dissolution of organic matter due to high pH. Consequently dissolved organic matter comes to the soil surface during summer on account of capillary rise and gets deposited in isolated patches on soil surfaces. These observations are in line with the findings reported in salt affected soils of Purna command area of Maharashtra (More *et al.*, 1988) and Harshi command area of Madhya Pradesh (Mediratta *et al.*, 1985). Similar observations were also made by Walia and Rao (1996).

The study site SOC content was low to medium in status. In salt-affected degraded areas, SOC (soil organic carbon) levels are likely to be affected by declining vegetation health and hence, decreasing biomass inputs and concomitant lower levels of organic matter accumulation. Moreover, potential SOC losses can be higher from dispersed aggregates due to sodicity (Vanessa *et al.*, 2006).

5.3.2 Available nitrogen

Considering the critical limits of <280, 280-560 and >560 kg ha⁻¹ as low, medium and high respectively proposed by Muhr *et al.* (1965), soil samples characterized have low to medium available nitrogen. The mean values of available nitrogen in soils ranged from 141.4 to 295.5 kg ha⁻¹ in surface and 82.5 to 232.5 kg ha⁻¹ in subsurface (Table 4.4). Similarly the available N content decreased regularly with depth in all the profiles. This might be due to decreasing trend of organic carbon with depth and cultivation of crops are mainly confined to the surface horizon (Rhizosphere) only and at regular interval the depleted nitrogen content is

supplemented by the external addition of fertilizers during crop cultivation (Satish Kumar and Naidu, 2012). Similar findings were reported by Parasuraman and Jayaraj (1982) and Gangappa (1989). The lower available nitrogen might be due to poor physical conditions of the soil, which might have accentuated the losses of soil nitrogen due to denitrification and volatilization loss reported by Nitant and Bhumbra (1974). The alkaline pH of the soil might have caused appreciable volatilization losses of nitrogen in the soils (Jenny and Raychaudhuri, 1960). It may also be due to reduction in nitrogen fixation by microorganisms, whose activity is limited due to reduced energy source caused by reduction in the growth of host plants under sodic conditions (Bharadwaj, 1975). The surface layers of all sites contained higher quantities of available nitrogen and invariably reduced down the depth (Lakshminarayana Murthy, 2003)

5.3.3 Available phosphorus

The available phosphorus content of surface, subsurface and profile samples was low to medium in range (16.8 to 30.9 kg ha^{-1} , 10.3 to 18.5 kg ha^{-1} and 1.3 to 25.8 kg ha^{-1} , respectively) except P_1 (56.3 kg ha^{-1}). The surface samples have high available phosphorus content compared to subsurface soil sample. The reduced available P status observed in the soils investigated could be ascribed to the precipitation of added phosphorus as calcium and magnesium phosphate of low solubility. Similar results were reported by Ravi Kumar *et al.* (2007), Vijaya Kumar *et al.* (2013) and Murthy, (1988).

The exceptionally high phosphorus in surface soil of site 1 may be due to high application of the phosphatic fertilizers year after year. The farmers are using only diammonium phosphate as a source of nutrients in adequate quantity. As a result, P is available in medium range.

5.3.4 Available potassium

The available potassium content in soils of study area were low to high and mean values in surface samples varied from 179.1 to 283.4 kg ha^{-1} and in subsurface it ranged from 160.9 to 242.9 kg ha^{-1} . As per the critical limit proposed by Mohr and Van Barren (1954), soils of the study area were well supplied with available potassium, particularly in the surface layers. Occurrence of potash-rich micaceous and

feldspar minerals in these salt affected soils (Kapoor *et al.*, 1981) and dissolution of large amounts of such minerals under sodic conditions (Pal, 1985) besides, regular addition through fertilizers could have led to higher potassium availability. These results are in line with those reported by Ravikumar (2006) and Roy and Landey (1962).

The exceptionally very low potassium status observed in P11 (site 4) might be attributed very high sand content in the profile as it was situated very close to natural nala. The vertical distribution was not consistent but in general the lower available K content was observed in lower depths compared to surface soil. Increase in accumulation of exchangeable sodium at lower depths might have reduced the downward mobility of this nutrient (Chhabra, 1985).

5.3.5 Available sulphur

The available sulphur content of soil varied from low to high in status in the study area. The maximum content was noticed in surface layer and it decreased with the depth in all the profiles due to higher amount of organic matter in surface layers than in deeper layers. Among the sites, site 1 showed slightly higher sulphur content (10.31 to 12.83 mg kg⁻¹) in surface compared to other sites due to higher organic matter content in that site (Table 4.3). The higher concentration of available S in these soils might be attributed to higher amount of soluble salts in these soils. Similar results were reported by Kour and Jalali (2008) and Vijaya Kumar *et al.* (2013). Tawande *et al.* (1976) reported that sulfur content depends on the combined action of factors namely nature of parental material, rainfall, clay and organic matter content. The findings of present study are in collaboration with the finding of Das *et al.* (2012).

5.3.6 Micronutrients

The status of available Fe, Mn, Zn, Cu and B in the study area was above the critical limit. The content of these nutrients was higher in the surface layer compared to lower layers. The increase in content of these nutrients might be attributed to flooded condition during crop growth period. Anand Swarup (1982) observed similar increase in gypsum amended sodic soil in paddy field. Application of gypsum and farmyard manure further enhanced the availability of these nutrients. Application of

zinc sulphate at the rate of 20 kg ha⁻¹ to rice crop could substantially raise the available Zn status (DTPA extractable) of the soil (Anand Swarup, 1982).

The higher content of micronutrients in surface soil is due to high OC. The decreased content in subsurface is due to precipitation and higher pH of the soils which decreased the availability (Vijaya Kumar *et al.*, 2013). The distribution of micronutrients in profile samples did not show a definite pattern but they were abruptly decreased. It might be due to accumulation of organic carbon in the surface horizons (Geetha Sireesha and Naidu, 2013).

5.4 Classification of salt affected Soils

In the traditional classification (Richards, 1954), the ECe and the ESP of associated soils were used as criteria for grouping salt-affected soils. In this ECe was fixed at 4 dS m⁻¹ to distinguish saline soils from non-saline ones. The salt sensitive plants, however, can be affected in soils having ECe of only 2 to 4 dS m⁻¹. However, the terminology committee of the soil science society of America has lowered the boundary between saline and non-saline soils to 2.0 dS m⁻¹ in the saturation extract (Girdhar, 1993).

The criteria proposed by USDA (Richards, 1954, Handbook No. 60) for classification of salt-affected soils is given below.

Classification	Normal Soils	Saline Soils	Sodic Soils	Saline-Sodic Soils
Traditional Classification	ECe <4 ESP <15	ECe >4 ESP <15	ECe < 4 ESP >15	ECe >4 ESP >15
Proposed Classification	ECe <2 ESP <15	ECe >2 ESP <15	ECe <2 ESP >15	ECe >2 ESP >15

Based on the values of pH, ECe and ESP, the surface and subsurface soils classified into saline, sodic and saline-sodic using the criteria proposed by Girdhar (1993). The per cent of samples in different categories are presented below.

Classification	Saline Soils (%)		Sodic Soils (%)		Saline-Sodic Soils (%)		Normal soils (%)	
Depth	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
Site 1	26	16	13	11	32	45	29	28
Site 2	15	15	15	9	42	45	28	31
Site 3	50	50	9	6	6	5	35	39
Site 4	-	-	-	-	83	78	17	22

The soils of P₄, P₆ and P₇ are classified as saline and P₁, P₂, P₃, P₈, P₉, P₁₀ and P₁₁ are classified as saline-sodic according to USDA (Richards, 1954) and P₅ is classified as non-saline and non sodic but alkaline in reaction.

II. Field Experiment:

5.5 Effect of levels and ratios of NPK application on growth and yield of paddy

The results of field experiments carried out to study the effect of nutrient levels and ratios on growth, yield and nutrient uptake by rice in Southern dry zone of Karnataka with eighteen different ratios of nitrogen (N) phosphorus (P₂O₅) and potassium (K₂O) and one control conducted at Zonal Agricultural Research Station, V.C. Farm, Mandya on sandy clay loam soil during *Kharif* 2013 and summer 2014 are discussed in this chapter. This study was initiated to know whether higher NPK fertilizer levels and ratio to rice crop is profitable over recommended fertilizer ratio of 2:1:0.8 (125 kg N, 62.5 kg P₂O₅ and 50 kg K₂O ha⁻¹) in sodic soil condition.

5.5.1 Growth and yield parameters.

Application of levels and ratios of NPK significantly influenced the growth and yield parameters of paddy (Table 4.25 to 4.28). Irrespective of the levels and ratios of NPK application, significantly influenced the growth and yield parameters like plant height (57.6 to 66.6 cm), number of tillers (12.5 to 16.9), number of productive tillers (10.5 to 14.9), panicle length (19.1 to 22.9 cm), number of seeds per panicle (156.2 to 179.6) and thousand grain weight (24.8 to 28.4 g) compared to

control (46.2 cm, 7.6, 6.8, 16.0 cm, 138.6 and 23.5 g, respectively) due to better supply of essential nutrients (NPK) which are required for plant growth.

Among the levels and ratios, 150:50:50 kg N:P₂O₅:K₂O ha⁻¹ (3:1:1) gave the highest plant height (66.6 cm), number of tillers (16.9), number of productive tillers (14.9), panicle length (22.9 cm), number of seeds per panicle (179.6) and thousand grain weight (28.4 g) and the dose 100:37.5:50 gave the lowest plant height (57.6 cm), number of tillers (12.5), number of productive tillers (10.5), panicle length (19.1), number of seeds per panicle (156.2) and thousand grain weight (24.8 g).

5.5.2 Grain and straw yield.

Yield of paddy crops on salt affected soils was very low because of excess salts or high ESP as compared to normal soils. Such lower yield of crop on salt affected soils have been reported by several researchers Abrol and Bhumbla (1979), Srinivasa (1999), Lal Bahadur *et al.* (2013), Sunitha (2008), Jagtap *et al.* (2007) from different parts of the world . Amelioration of salt affected soils require flushing out of excess salts and/or removal of Na from exchange site to a desired level using amendment followed by leaching of Na from the field (Kuligod *et al.*, 2002). In command area, the adoption of rice based cropping system is recommended practice as rice is tolerant to exchangeable Na and its reclaiming effect, so that rice can be raised during the process of leaching. The mineral nutrition in optimum ratios and levels is fundamental to higher crop production in recently reclaimed soils as the nutrients are lost through leaching during the course of reclamation of salt affected soil (Mehdi *et al.*, 2007).

Application of N, P and K at different levels and ratios significantly increased the grain (4.38 to 5.37 t ha⁻¹) and straw yield (5.43 to 6.79 t ha⁻¹) as compared to control (2.82 t ha⁻¹ and 3.69 t ha⁻¹) in gypsum amended sodic soils (Table 4.28 and Fig. 18). The significantly lower grain and straw yield obtained in no fertilizer (control) plot might be attributed to low nutrient availability due to leaching of native nutrients during the course of leaching process. These findings are in line with those reported by Waseem (2004) and Singh *et al.* (2005). On the other hand higher yield in fertilized plots was attributed to application of nutrients from external source. Similar results were reported by Singh *et al.* (2005) and Hayee *et al.* (1989). Thus it clearly indicates gypsum application is not just sufficient to get economic crop yield, while

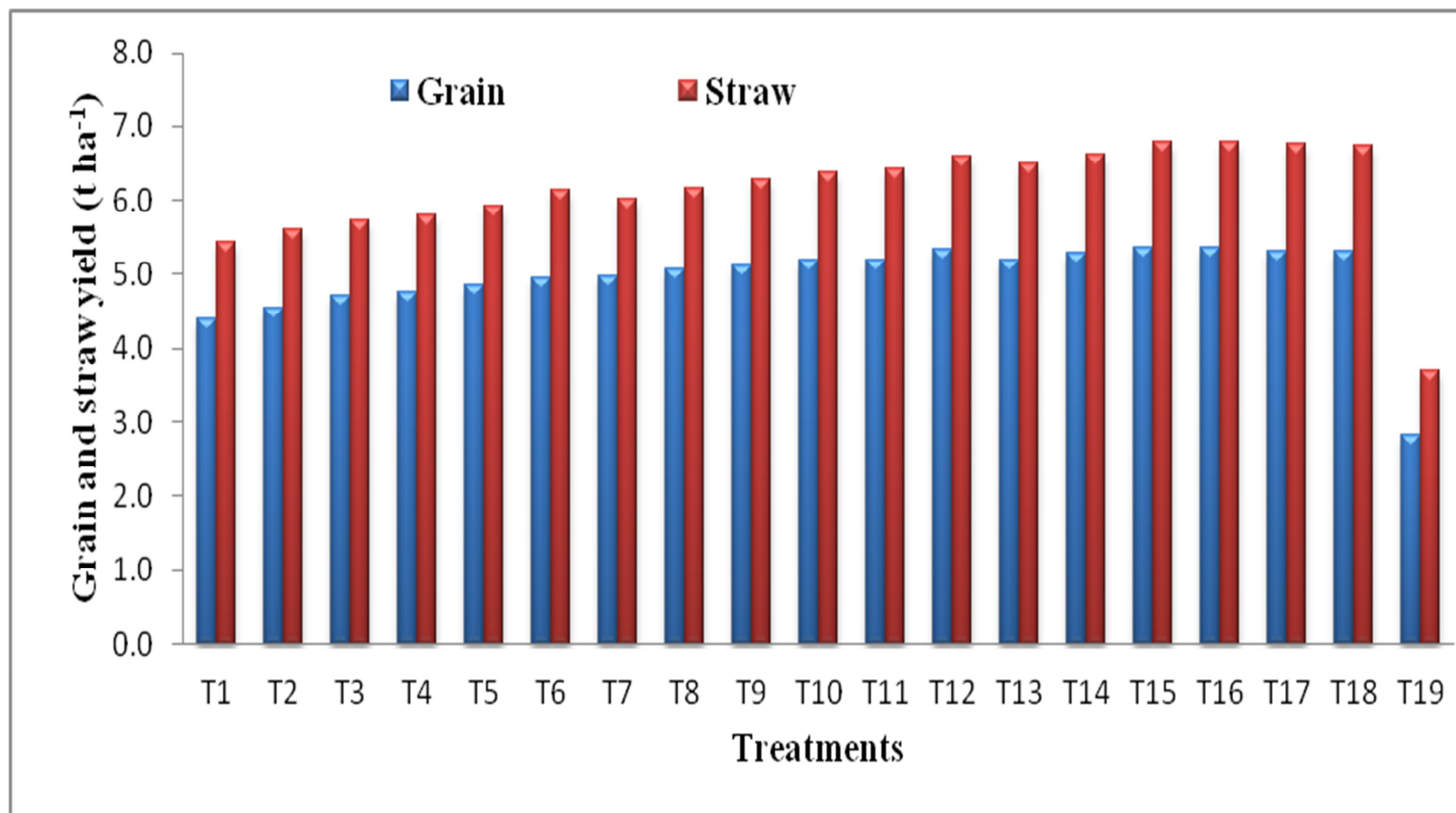


Fig. 18: Effect of nutrient levels and ratios on grain and straw yield of rice crop.

application of nutrients from external source is all the more vital to harvest better crop. These results are in line with those reported by Satyanarayana *et al.* (2002), Yaduvanshi (2003) and Lal Bahabur *et al.* (2013).

The higher grain and straw yield obtained due to application of nutrients might be attributed to improvement in growth (Table 4.25) and yield parameters (Tables 4.26 and 4.27) consequent to improved availability of nutrients. The improved nutrient availability is resulted in the better uptake of nutrients (Table 4.37 to 4.40) and nutrient use efficiency (Table 4.41).

Among different levels and/or ratios of NPK the grain and straw yield varied with minimum of 4.38 and 5.43 t ha⁻¹, respectively in the treatment receiving 100:37.5: 50 kg N: P₂O₅: K₂O ha⁻¹ to a maximum of 5.37 and 6.79 t ha⁻¹, respectively in the treatment that received 150:50:50 kg N:P₂O₅:K₂O ha⁻¹. The variation in the yield among the fertilizer treated plots might be attributed to different levels of nutrients supplied in different ratios. Similar effect was also observed in growth and yield parameters (Tables 4.25 to 4.27). Higher increase in yield was noticed with increasing levels of nitrogen (100, 125 and 150 kg ha⁻¹) compared to the increase observed with levels of P and K. The increase in yield with increasing levels of N might be attributed to increased growth and yield attributes, uptake of nutrients and nutrient use efficiency. Similar results were reported by Lal Bahabur *et al.* (2013), Srinivasa (1999), Sabir *et al.* (2007). Mehdi *et al.* (2007) reported that application of N at 175 kg ha⁻¹ level increased the yield of rice markedly in recently reclaimed sodic soil. Manzoor *et al.* (2006) observed such an increase in recently reclaimed saline-sodic soils. Such increase that in yield with increasing level of N indicates the level of N is a key for successful crop production in a recently ameliorated sodic soil.

The response of rice to additional application of nitrogen as basal dose and top dress particularly under sodic situation has resulted in incessant and more availability of nitrogen to the crop. In general, greater utilization of phosphorus and potassium in the presence of higher amount of nitrogen led to the improvement in different growth and yield components. The overall improvement in growth and yield components in the treatment receiving NPK fertilizer in the ratio of 3:1:1 (150 kg N, 50 kg P₂O₅ and 50 kg K₂O ha⁻¹) might be the reason for higher grain yield.

Both grain and straw yield of rice obtained with the application of 37.5 kg ha⁻¹ level was lower at all the N levels compared to 50 or 62.5 kg ha⁻¹ P₂O₅ level, however there was no significant difference in yield between these two levels of phosphorus. Similarly at any level of P application increasing the rate of K₂O application from 50 kg ha⁻¹ to 75 kg ha⁻¹ increased both grain and straw yield marginally. Thus the results indicate that application of NPK in the ratio of 125:62.5:75 kg ha⁻¹ (2:1:1.2) and 150:50:50 kg ha⁻¹ (3:1:1) is the better NPK level that supplies nutrients in optimum ratios to get profitable yield in gypsum amended soil along with FYM and zinc sulphate application

The significant increase in paddy yield in these soils could be attributed to the direct effects of the introduction of open surface drainage system which in turn lowered the soil salinity by leaching out the soluble salts from the root zone, thereby creating favorable conditions in the root zone, but also making nutrients available to the plants resulting in optimum plant growth and yield. Further, the shallow water table helped to overcome the excessive drainage and also remove the harmful salts that are brought in by the irrigation water there by creating favorable conditions in the soil root zone to establish second crop successfully in the second season after harvest of *Kharif* rice.

Grain and straw yield obtained due to application of recommended dose of fertilizer (125:62.5:50 kg NPK ha⁻¹/2:1:0.8) were 5.19 and 6.42 t ha⁻¹, respectively, which increased significantly to 5.37 and 6.79 t ha⁻¹ due to application of 150: 50 : 50 kg NPK ha⁻¹/ 3:1:1 but it was on par with the yield obtained due to application of 125:62.5:50 kg NPK ha⁻¹/2:1:0.8. The extent of increase in grain and straw yield due to application of NPK at the level of 150:50:50 kg NPK ha⁻¹ (3:1:1) compared to yield obtained with RDF was 3.5 and 5.8 per cent, respectively. Thus the results indicate that application of NPK in the ratio 2:1:1.2 (125:62.5:75 kg ha⁻¹) and 3:1:1 (150:50:50 kg ha⁻¹) is the better NPK level that supplies nutrients in optimum ratios to get profitable yield in gypsum amended soil along with FYM and zinc sulphate application.

The yield of rice increased with increasing level of N (100, 125 and 150 kg ha⁻¹ soil). The reduction in yield was attributed to nutritional imbalance and higher osmotic potential and toxicity of specific ion. While the increase in yield with

increasing level of N was attributed to increase in CEC of root (Bear, 1964) and increased root growth and /or volume played a key role in inducing the tolerance against the salt stress. Similar reduction in yield of rice has been reported by Arjunan and Chandrasekaran (1998). The results are in agreement with those reported by Malik and Shah (1996) for wheat and Nadeem *et al.* (1995) for rice crop.

5.6 Effect of NPK levels and ratios on nutrient uptake by paddy

5.6.1 Total nutrient uptake by paddy

The uptake of nitrogen, phosphorus and potassium by the crop at the time of harvest due to NPK and gypsum application during reclamation of sodic soil are presented in Table 4.37 and Fig. 19. At all the levels and ratios of NPK, major nutrients (NPK) uptake by rice was significantly higher compared to unfertilized control. This could be attributed to the fact that, fertilizer provides all the essential nutrients in sufficient quantities for better uptake. Application of NPK @ 150:50:50 kg ha⁻¹ recorded significantly higher uptake (129.5 kg ha⁻¹) compared to RDF (113.0 kg ha⁻¹). The increased uptake of nutrients might be attributed to improved nutrient use efficiency (Table 4.41), and higher yield (Table 2.28). The improved uptake could also be attributed to enhanced availability of major nutrients due to their application from external source besides decrease in pH and lowering of ESP due to application of gypsum (Table 4.52), which has resulted in better growth condition consequently resulting in higher uptake. Chauhan (1995) reported that application of gypsum increased the uptake of N, P, K and Zn by rice crop in sodic soil due to decrease in pH.

Similarly calcium, magnesium, sulfur and micro-nutrients uptake was also found highest in NPK treated plots compared to control (Table 4.30 to 4.32). Higher nutrient uptake by paddy in NPK treatments might be attributed to lowering of harmful effect of interfering factors which resulted in better crop growth and yield besides improved availability of nutrients. Results of enhanced uptake of nutrients due to the application of NPK and organic manures was reported by Korndorfer and Anderson (1993) and Mahendra (2007).

The higher availability of nutrients to crops may also be due to application FYM at 10 t ha⁻¹ and zinc sulphate at 20 kg ha⁻¹. The mineralization of applied

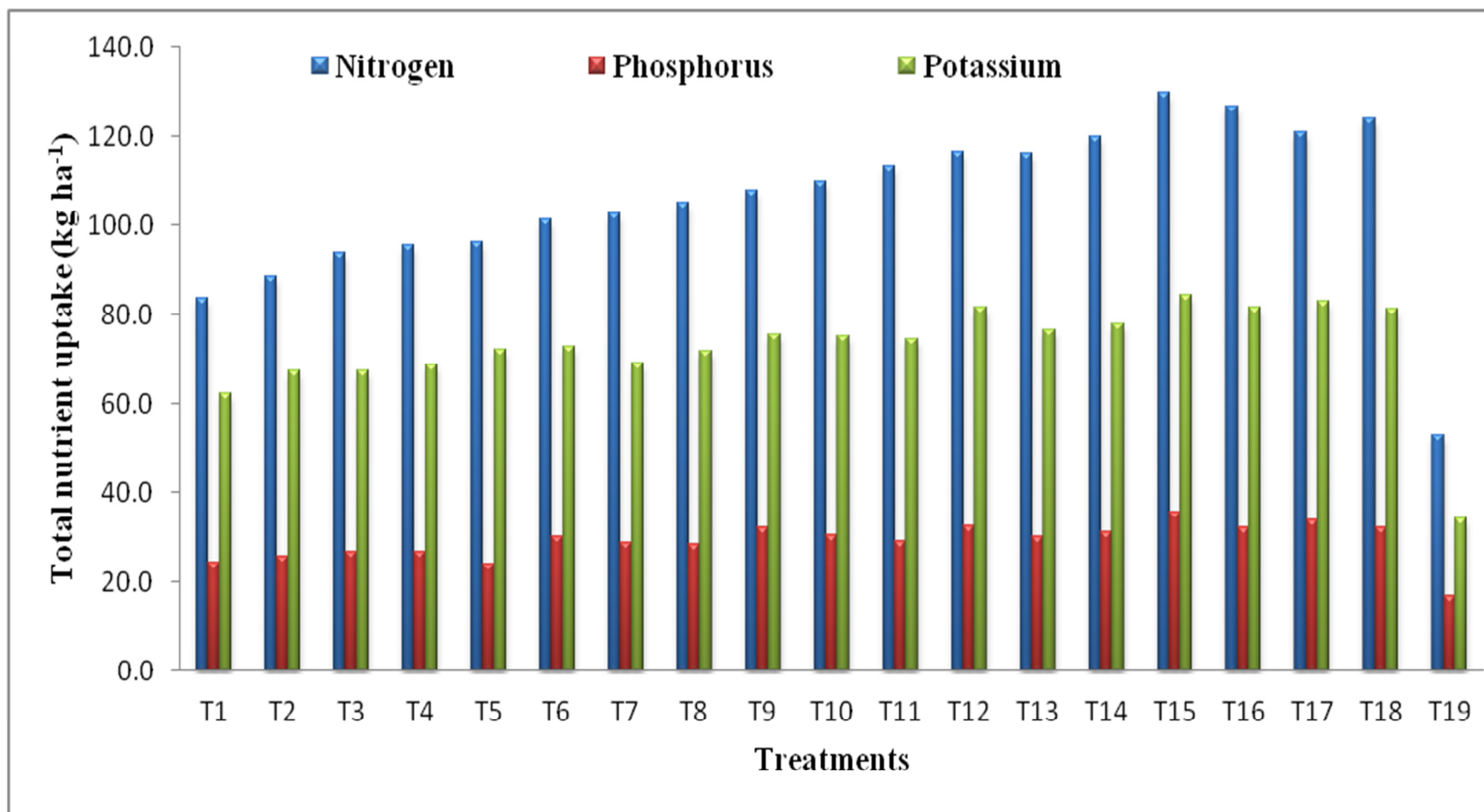


Fig. 19: Effect of nutrient levels and ratios on nitrogen, phosphorus and potassium uptake of rice crop.

organic matter released the nutrients contained in them, besides the acids that are released during the decomposition might have helped in solubilizing the unavailable forms of nutrients, thus increasing the availability of nutrients.

5.7 Effect of NPK levels and ratios on nutrient use efficiency

Nutrient use efficiency is calculated based on differences in crop yield and/or nutrient uptake between fertilized plots and an unfertilized control (difference method) to estimate crop and soil recovery of applied nutrients. In salt affected soils the unfavourable soil condition usually results in lower recovery of applied nutrients.

The pooled analysis of two seasons data revealed that highest N, P and K use efficiency (0.51, 0.47 and 1.0 kg kg⁻¹ NPK, respectively) was observed in the treatment T₁₅ receiving NPK ratio of 3:1:1 (150 kg N, 50 kg P₂O₅, 50 kg K₂O ha⁻¹) compared to all other NPK ratios and levels (Table 4.33 and Fig. 20). The higher recovery of applied nutrients in nutrient applied plots might be attributed to better dry matter production coupled with higher nutrient uptake consequent to decreased chemical competition for absorption due to reclamation measures adopted and improved nutrient levels and ratios. This might be due to maximum absorption and utilization of applied nutrients. These results are in accordance with earlier findings of Dinesh Sharma *et al.* (2012).

5.8 Effect of NPK levels and ratios on soil properties

5.8.1 Soil pH

A reduction in soil pH after the harvest of rice crop has occurred in the surface layer (Table 4.42 and 4.43) during the first season. The reduction in soil pH was attributed to displacement of exchangeable Na by the calcium ion of gypsum and subsequent formation of sodium sulphate which get leached out of soil through drainage. Similar decrease in soil pH from the initial value of 10.2 due to application of gypsum along with green manure and FYM was observed by Anand Swarup (1991) in sodic soils of Karnal. While Chauhan (1995) observed similar decrease in pH (from 10.5-8.6) with the application of gypsum @ 50per cent GR for alkali soils of Faizabadh in Uttar Pradesh.

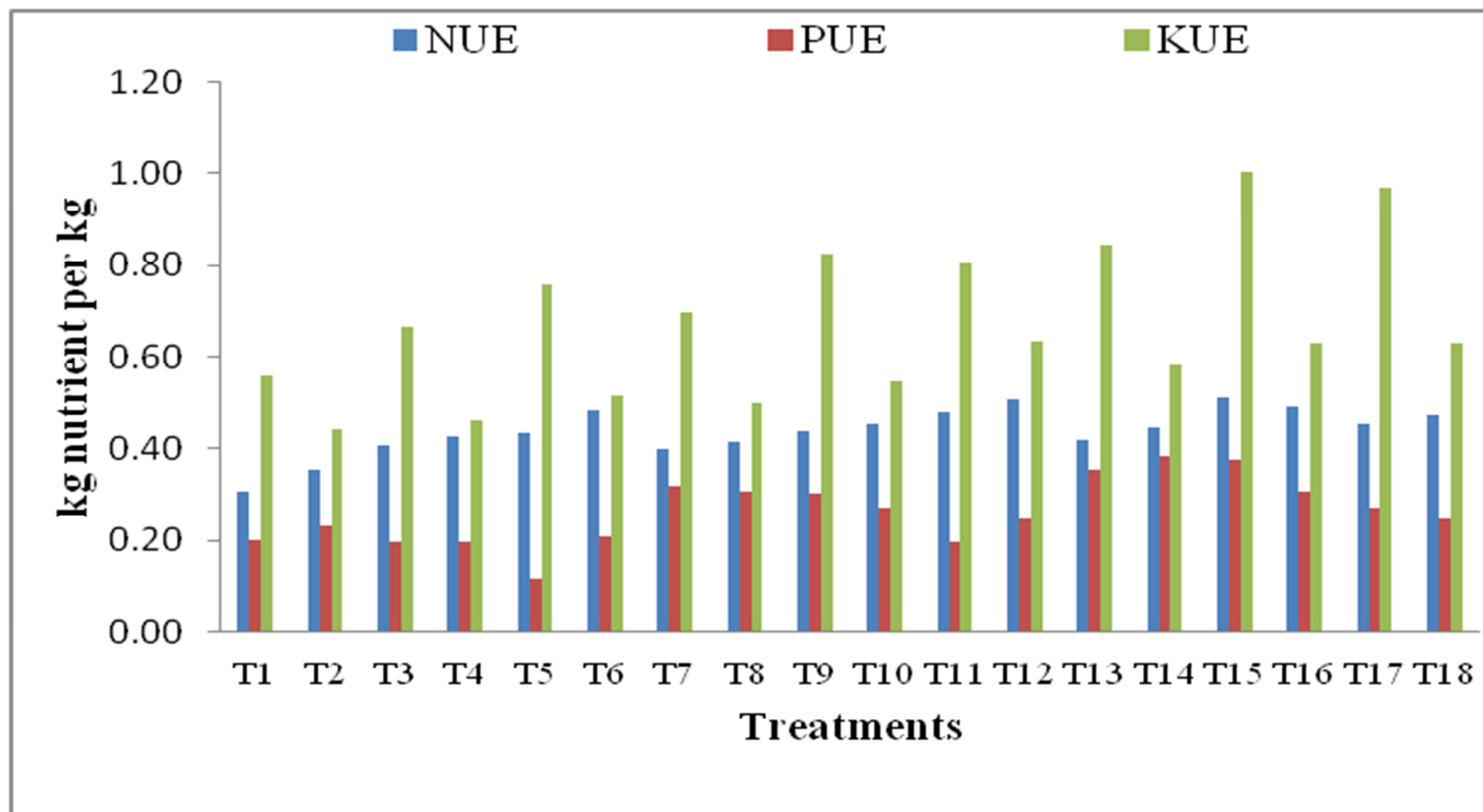


Fig. 20: Effect of nutrient levels and ratios on nutrient use efficiency of rice crop.

In general, after the harvest of summer 2014 crop the soil pH increased marginally compared to first season, however it was still lower than the initial soil pH (8.6). The changes in soil pH in cropped field are associated with difference in cation/anion uptake and release of H^+ or OH^- (HCO_3^-) by plant. The release of protons or hydroxyl ions to neutralize the imbalance results in pH changes. When more cations are absorbed H^+ is released by roots to keep ionic balance and pH decreases, similarly when more anions are absorbed, OH^- are released and pH increases. Besides the effect of crop, it could be attributed partly to formation of bicarbonate with dissolution of carbonate as a result of increase in CO_2 concentration might have contributed to the observed increase in soil pH after the harvest of summer crop. Partly it could be attributed to addition of alkali salts through irrigation water and seepages from adjoining area. However, the recorded pH in the soil after the harvest of the crop did not cause stress to the crop plants as it was well below the critical level for stress.

For rice, soil salinity beyond $EC_e \sim 4 \text{ dS m}^{-1}$ is considered moderate salinity while more than 8 dS m^{-1} becomes high. Similarly, pH 8.8-9.2 is considered as non-stress while 9.3-9.7 as moderate stress and equal or greater than 9.8 as higher stress. Extreme high salt stress conditions kills the plant but the moderate to low salt stress affect the plant growth rate and thereby manifest symptoms which could be associated with morphological, physiological or biochemical alterations.

5.8.2 Electrical conductivity

The initial EC_e value (2.4 dS m^{-1}) increased substantially after the first season crop (3.8 to 5.4) then decreased (2.12 to 3.1) but was still slightly higher than initial value (Table 4.42 and 4.43). The increase in electrical conductivity in gypsum amended plots may be attributed to addition of gypsum to soil reclamation, resulting in slight build up in salt content of soil. But the extent of buildup was below the critical limit (4 dS m^{-1}) after the second season. Addition of NPK nutrients through fertilizers at varied levels and ratios further increased the EC_e value compared to unfertilized plot due to direct addition of salts through fertilizers and release of ions from insoluble form upon submergence. Further, the electrical conductivity increased with increasing levels of fertilizers.

Acidic nature of gypsum along with good amount of calcium helped in solubilization of free lime content of soil which replaced the sodium on exchange complex might have contributed for increase in electrical conductivity of soil. Lakshmi Prasanna (1991) revealed that decomposition of organic matter in the soil released the acids. The organic acids dissolved the saline-sodic salts which may increase the electrical conductivity of soil.

5.8.3 Organic carbon

The organic carbon content of soil increased from the initial level of 3.1 g kg⁻¹ to medium status after harvest of the crops (Tables 4.42 and 4.43). The increase in organic carbon content might be attributed to improved soil condition due to application of gypsum at the rate of 100% GR and FYM @ 10t ha⁻¹. The organic carbon content increased further due to application of different levels and ratios of NPK. The increase in organic carbon content of soil with the addition of nutrients might be attributed to increased root biomass due to improved availability of nutrients upon application as a result of favorable conditions.

The results are in line with Trilok Nath Rai *et al.* (2010) who reported increase in organic matter content of soil due to application of organic manures and fertilizers.

5.8.4 Available major nutrient status

The available major nutrients status of soil after the harvest of crop increased significantly due to application of different levels and ratios of NPK as compared unfertilized control during both the seasons (Table 4.44 and 4.45). Though the available major nutrients status of soil decreased in control plot, it was higher in fertilized plots compared to initial level. This decrease in control plot might be attributed to crop uptake and loss of nutrients during leaching from native source. Similar increase in nutrient content was observed by Mehdi *et al.* (2007). The variation observed in the available N status after the harvest of crop may be ascribed to variation in removal of N by crop. There was no definite trend in the available N status in soil after the harvest of crop due to treatment effect.

After the harvest of first crop, the available phosphorus content of soil decreased from its initial status in all the ratios due to removal of phosphorus by the crop and P fixation by calcium applied in the form of gypsum. After the harvest of

second crop, P availability increased over the initial value. The increased availability of P in soils saturated with sodium was attributed to accelerated dissolution of Ca-P compounds or complexes. Similar results were reported by Singh *et al.* (1969) and Srivastava and Srivastava (1993).

The available potassium content of soil increased significantly with increased levels of K application in all plots. At harvest stage, pooled analysis of two years data (2013 and 2014) showed the available potassium content in soil increased from its initial status in all the treatments and it varied from 171.3 kg ha⁻¹ in control to 283.6 kg ha⁻¹ in the treatment with the fertilizer ratio of 2.5:1:1.5 (125 kg N, 50 kg P₂O₅, 75 kg K₂O ha⁻¹).

The lower available major nutrients status at 150: 50: 50 kg N:P₂O₅:K₂O ha⁻¹ level could be due to higher nutrient use efficiency. The variation in fertilized plot might be attributed to variation in leaching loss of these nutrients and crop removal.

In addition to calcium, the gypsum used in the present investigation contained enough sulphur which upon oxidation acidified the medium and solubilized the native calcium carbonate reserves of the soil. The released calcium and magnesium replaces the sodium on the exchange complex which in turn improved the chemical properties of soil. Application of gypsum and nutrients helped in reducing the pH and ESP. Gypsum application gradually decreased the soil pH, decreased the exchangeable Na⁺, ESP, increased the CEC and in turn the nutrient availability. Similar results were reported by Srinivasa (1999), Yaduvanshi and Swarup (2005), Sabir *et al.* (2007), Suma and Savitha (2010) and Dinesh Sharma *et al.* (2012).

5.8.5 Exchangeable calcium, magnesium and available sulphur content of soil

Application of gypsum significantly increased the exchangeable calcium, magnesium and available sulphur content of soil in all the treatments during 2013 and 2014 compared to initial values of soil (4.8 and 3.6 cmol(p⁺)kg⁻¹ soil) (Table 3.4, 4.46 and 4.47). Application of NPK at different levels and ratios has further increased the exchangeable calcium and magnesium. Such increase over the control plot (no fertilizer) might be attributed to application of phosphorus through single super phosphate.

Application of gypsum might have resulted in higher dissolution of free CaCO_3 , thus increasing the calcium on exchange sites (due to its divalent nature, preferentially adsorb on clay surface). The acidic nature of gypsum might have solubilized the native free lime which released $\text{Ca}+\text{Mg}$ in free ionic forms which might have also contributed for increased $\text{Ca}+\text{Mg}$ on exchange sites with the replacement of exchangeable sodium. Similar observations were made by Srinivasa (1999) and Sunitha (2008) who reported that application of gypsum increased the Ca and Mg content of soil. The sulphur content of soil after harvest of summer 2014 crop decreased compared to *Kharif* 2013 crop significantly may be due to crop uptake and leaching of sulphur as sodium sulphate.

5.8.6 Exchangeable sodium content of soil

Exchangeable sodium content of soil at harvest of crop was significantly influenced by treatments (Table 4.48 and 4.49). Exchangeable Na content in soil decreased (1.6 to 2.07) from its initial level of 2.9. The decrease might be ascribed to application of gypsum to reclaim the soil at 100 % GR level. Application of gypsum resulted in higher exchange of sodium by calcium and subsequent leaching with good quality water thus replacing the sodium from the exchange sites. The Na^+ and K^+ have much higher mobility than Ca^{2+} and Mg^{2+} in the soil. Similar observations were also reported by Mahmoodabadi *et al.* (2013). Gypsum when applied to soil undergoes solubilization producing calcium and sulphate ions. The calcium ions in solution replace the sodium on the exchange complex which is then leached out as sulphate salt. Similar results were also reported by Somani (1990) and Srinivasa (1999) that application of gypsum decreased the exchangeable sodium content of soil.

5.8.7 Micronutrients

DTPA extractable micronutrients content of soil as influenced by application of gypsum and NPK is presented in Tables 4.48, 4.49, 4.50 and 4.51. Significantly higher amount of micronutrients like Fe , Mn , Zn , Cu and B were recorded in treatments which received NPK at different levels and ratios in gypsum and FYM amended soil compared to unfertilized gypsum amended control plots. The increase in micronutrient status in soil might be attributed to application of FYM to all the plots and solubility of these due to submergence. Buildup of these metallic cations was

recorded in the soil as a consequence of use of gypsum and farm yard manure might be attributed to an increase in organic carbon content of soil resulting in higher adsorption of the metallic cations. Totawat (1991), Marsh and Siceama (1997) and Patil *et al.* (2004) also reported that among soil properties, organic carbon showed significant positive correlation with most of the trace elements was the most influential parameter on availability of these elements. The results of the present investigation are also in agreement with the findings of Bharadwaj *et al.* (1994), Jagtap *et al.* (2006) and Vijaya Kumar *et al.* (2013).

5.8.8 Effect of different levels of NPK and gypsum application on ESP of soil

Application of gypsum and NPK at different quantities significantly reduced the ESP of both the soils (Table 4.52). The lower exchangeable sodium percentage in both the seasons was recorded in surface (0-15cm depth) soil which received gypsum @ 34.4 t ha⁻¹ and calculated quantities of NPK along with 10 t ha⁻¹ FYM. Chauhan and Tripathi (1983) reported that application of gypsum @ 5 to 20 t ha⁻¹ followed by leaching markedly reduced the soluble salt content, and exchangeable sodium percentage. He also reported that gypsum @ 100% GR and leaching during two successive monsoon seasons with the raising of two crops (barley and rice) although reduced salt and boron content to nearly normal level up to 92 cm depth but pH and ESP were affected in the top 23 cm soil only.

Hence, gypsum treatment is considered optimum for reducing the ESP to a desired level under field conditions. The results are in accordance with the findings of Chhabra and Thakur (2000), Abdel-Fattah (2012), Trilok Nath Rai *et al.* (2010). With the increase in days after application of gypsum there was gradual reduction in ESP.

5.9 Effect of different levels and ratios of NPK and gypsum application on economics of rice production

The economic analysis based on gross monetary returns and net monetary returns revealed that the NPK ratio of 3:1:1 (150 kg N, 50 kg P₂O₅, 50 kg K₂O ha⁻¹) was found to be most economical fertilizer management practice over all the other fertilizer management practices involving RDF (125 kg N, 62.5 kg P₂O₅, 50 kg K₂O ha⁻¹) and other levels of NPK as it resulted in the highest gross income and benefit

cost ratio (1.86) (Table 4.45 and Fig. 21). The higher monetary benefit is accrued as a result of higher yield obtained in the above treatment that contributed more return over other levels.

The highest net return and benefit to cost ratio were recorded with $N_{150}P_{50}K_{50}$ kg ha⁻¹ (Table 4.53). The increase in net return and B:C ratio with application of $N_{150}P_{50}K_{50}$ kg ha⁻¹ might be due to higher yields in these treatments that contributed more returns over other levels. Similarly, application of NPK applied to rice crop increased the net return and benefit: cost ratio, giving the highest return over the unfertilized control (B:C ratio 1.08).

Practical utility of research work

From the physical and chemical characteristics of the soils studied, it has been found injudicious use of canal water without adequate drainage conditions are responsible for the development of sodicity in the study area. The salinity/sodicity is a problem in the lowland portion of site 1, site 2 and site 4 compared to upland and midlands. Injudicious use of irrigation water inadequate and improper drainage may further aggravate the situation. So, it is suggested that in the command area, irrigation water needs to be released in a controlled manner from canal with enough provision for proper drainage network.

Based on the results of field experiment, higher grain yield (5.37 t ha⁻¹) of rice along with higher straw yield (6.79 t ha⁻¹), higher nutrient use efficiency and higher net monetary returns (Rs. 34,229) and highest benefit cost ratio (1.86) can be obtained with fertilizer management practices involving application of 150 kg N, 50 kg P₂O₅ and 50 kg K ha⁻¹ (NPK fertilizer ratio of 3:1:1) under gypsum amended sodic soil condition.

Future line of work

1. The best NPK ratio of 3:1:1 (150:50:50 kg NPK ha⁻¹) which out yielded other ratios in the present experiment needs to be validated in different locations having slight, moderate and severe sodic soil conditions.

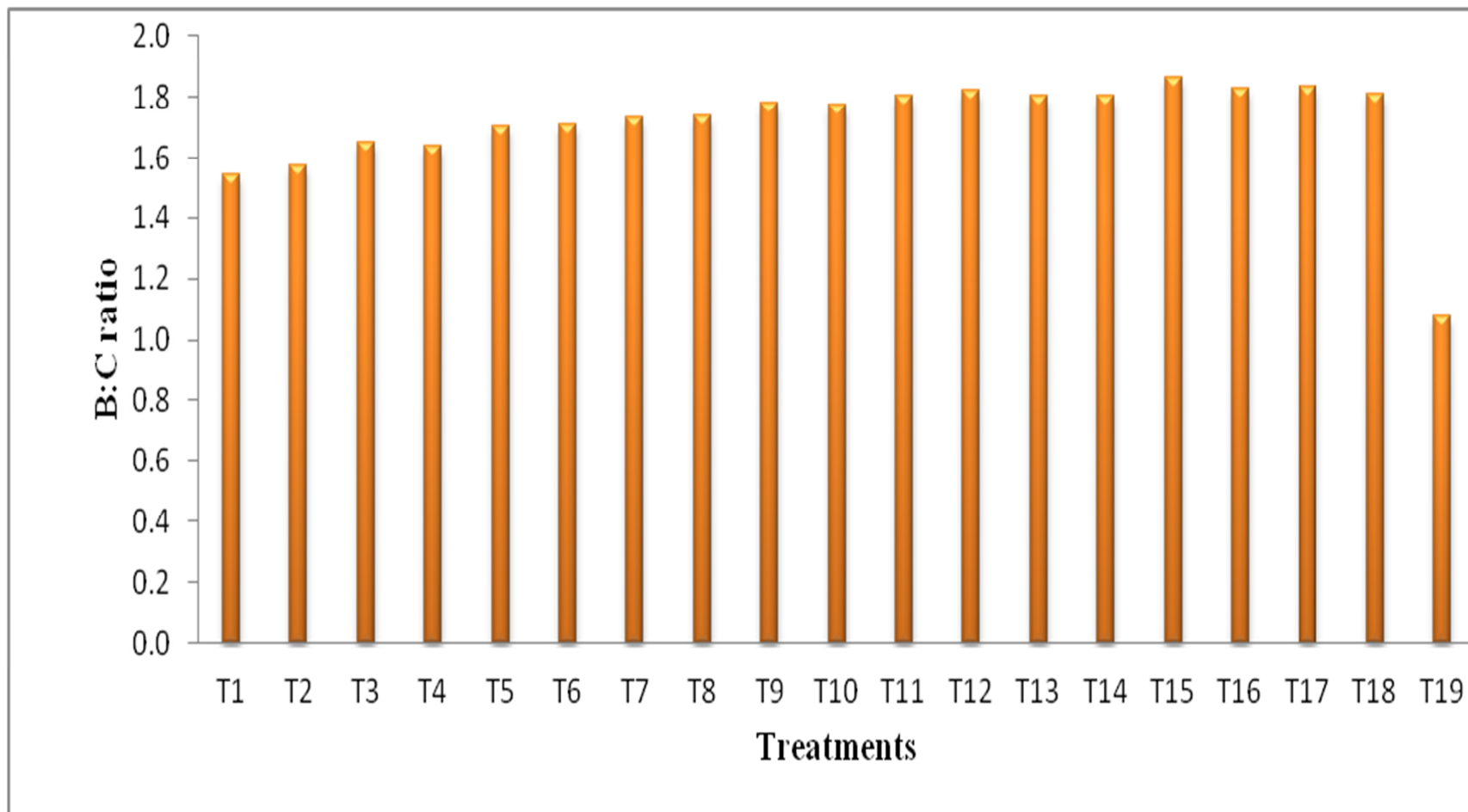


Fig. 21: Economics (Rs. ha⁻¹) of rice cultivation as influenced by nutrient levels and ratios in gypsum amended sodic soil.

2. The best NPK ratio (3:1:1) and level (150:50:50 kg NPK ha⁻¹) needs to validated in recently reclaimed salt affected soils.
3. Varietal and nutrient interaction needs to be studied in detail because different varieties of rice respond differently to applied NPK level and ratio of application.

VI. SUMMARY

Rice is a major staple food in Asia, where about 90% of the world's rice is produced and consumed. It is remunerative and promising crop under better management of fertilizers. Rice responds to management practices, especially for fertilizer and irrigation. Imbalance of nutrients especially, primary nutrients cause major problem on yield of crops. Therefore, study on the performance of rice with nineteen NPK levels and ratios in gypsum amended sodic soil were carried out during *Kharif* 2013 and summer 2014 at ZARS, V.C. Farm, Mandya.

The results obtained from the investigation and the conclusions that can be drawn from the above study are summarized in the following paragraphs.

6.1 Characterization of salt affected soils

- ❖ The clay content in the profile sample was in the range of 5.0 to 49.5 per cent in the surface horizons and 1.5 to 51.8 per cent in the sub soil horizons. The silt content ranged from 1.8 to 27.8 per cent with sub surface horizons having relatively more than the surface horizons. The sand content varied from 26.5 to 93.0 per cent. The bulk density varied from 1.12 to 1.85 Mg m⁻³ and water holding capacity varied from 20.6 to 56.0 per cent.
- ❖ The profiles show a high degree of variability in the vertical distribution of sand, silt and clay. The texture of soils was found to vary from sandy clay loam to clay. Clay content in most of the profiles was higher in the second layer. The texture of lowland physiographic units was finer than uplands.
- ❖ Free calcium carbonate content in profiles of site 1 varied from 0.2 to 5.2 per cent, in site 2 it varied from 0.5 to 1.3 per cent, in site 3 it varied from 0.2 to 3.2 per cent and in site 4 it varied from 0.3 to 5.0 per cent.
- ❖ Soil reaction in all the four sites was slightly acidic to alkaline (6.2 to 10.6) which may be attributed to the leaching of bases from the soil along with runoff and seepage of water occurring in the area. In lowlands, the soil reaction was distinctly alkaline (more than 8.1) due to the deposition of bases from the upland physiographic units.

The soil pH increased with depth in some profiles and decreased with depth in other profiles suggesting that there was no definite trend.

- ❖ The electrical conductivity of all the sites and profiles was low to high (0.4 to 11.7 dS m⁻¹) which indicates non-saline to saline nature of the soil. The ECe of profiles did not show any particular trend with depth.
- ❖ The CEC of soils ranged from 4.1 to 61.9 cmol(p⁺)kg⁻¹. The upland physiographic units were high in cation exchange capacity values than midlands and lowlands.
- ❖ In all the sites and profiles, calcium was the dominant cation followed by magnesium. The soils have high base status with dominant exchangeable cations in the order of Ca > Mg > Na > K. However, exchangeable Na was the dominant cation in surface and subsurface samples of low lands.
- ❖ The ESP of soils ranged from 1.1 to 58.6 in all the surface samples, whereas the value ranged from 1.8 to 46.9 in the profile samples. The uplands have low ESP than lowlands.
- ❖ Based on the values of pH, ECe and ESP, it was inferred that the per cent of surface soils belong to saline, saline-alkali and alkali soil was 26, 32, 13, in site one, 15, 42 and 15 in site two and 50, 6.0 and 9.0, respectively in site three. While the soils of site four had 83 per cent of the samples as saline-alkali in nature.
- ❖ From the pH, ECe and ESP values of subsurface samples, it was inferred that the per cent samples falling under saline, saline-alkali and alkali soil was 16, 45 and 11 in site one, 15, 45 and 9 in site two and 50, 5.0 and 6.0, respectively in site three. While the soils of site four had 78 per cent of saline-alkali in nature.
- ❖ The water soluble cations like calcium, magnesium, sodium and potassium were found to increase with increase in depth in all the sites and profiles. Among these cations, sodium was the most dominant cation in all the sites.

- ❖ The water soluble anions like carbonates, bicarbonates, chlorides and sulphates also recorded an increasing trend as that of cations along with the depth. Among the anions, chlorides and bicarbonates are the dominant ions in the water extract.
- ❖ The problem is more in the lowland condition in sites 1, 2 and 4 suggesting maximum of low land area had higher sodicity than upland.
- ❖ The organic carbon status of study area was low to medium. The content of SOC has decreased with depth.
- ❖ The available nitrogen, phosphorus and potassium were low, low to medium and medium respectively in status. The content of available N and P decreased vertically with depth.
- ❖ The available Ca, Mg and S status of the salt affected soils of the study area were low to medium.
- ❖ Based on the critical limits for DTPA extractable Zn, Mn, Cu, Fe and available B as 0.6 to 1.0, 2.0, 0.2, 2.5 to 4.5 and 0.5 mg kg⁻¹, respectively in salt affected soils, it can be concluded that, soils are deficient to sufficient with respect to zinc, iron and boron, where as copper and manganese are sufficient.
- ❖ These soils are chemically degraded due to the interaction of clay with sodium and other morphological features. This will create a great menace in future in this area, if suitable measures are not taken.

6.2 Response of rice to nutrient levels and ratios in gypsum amended sodic soils

- ❖ Application of different levels and ratios of NPK to rice crop improved the growth, yield and yield parameters studied over the unfertilized control plot.
- ❖ Significant increase in plant height, number of tillers hill⁻¹, number of productive tillers hill⁻¹, panicle length, number of seeds panicle⁻¹ and test weight were noticed with the treatment receiving NPK at different levels and ratios compared to control.

- ❖ The higher plant height (66.6 cm), number of tillers hill⁻¹ (16.9), number of productive tillers hill⁻¹ (14.9), panicle length (22.9 cm), number of seeds panicle⁻¹ (179.6) and test weight (28.4 g) were observed in the treatment T₁₅ receiving NPK @ 150 kg N, 50 kg P₂O₅ and 50 kg K₂O ha⁻¹ in the ratio of 3:1:1.
- ❖ The grain and straw yield of paddy increased significantly due to addition of NPK at different levels and ratios. The highest grain and straw yield (5.37 and 6.79 t ha⁻¹) was recorded in treatments receiving NPK @ 150 kg N, 50 kg P₂O₅ and 50 kg K₂O ha⁻¹ (3:1:1) and it was on par with T₁₆, T₁₂, T₁₈, T₁₇, T₁₄, T₁₀, T₁₁ and T₁₃.
- ❖ The total nitrogen (N), total phosphorus (P) and total potassium (K) uptake by rice crop increased with increasing NPK application rate over the control. The higher uptake of nitrogen, phosphorus and potassium (129.5, 35.6 and 84.3 kg NPK ha⁻¹) was recorded in the treatment receiving NPK ratio of 3:1:1 (150 kg N, 50 kg P₂O₅ and 50 kg K₂O ha⁻¹) as compared to treatments receiving other NPK ratios and control.
- ❖ The secondary and micronutrients uptake was also found to be high in rice crop, where combined application of gypsum and NPK was done.
- ❖ The nutrient use efficiency increased with increasing N levels and it decreased with increase in P and K levels above 50 and 75 kg ha⁻¹, respectively. Nitrogen, phosphorus and potassium fertilization with ratio of 3:1:1 (150 kg N, 50 kg P₂O₅ and 50 kg K₂O ha⁻¹) recorded higher nutrient use efficiency (0.51 kg N kg⁻¹, 0.73 kg P₂O₅ kg⁻¹ and 1.00 kg K₂O kg⁻¹, respectively) compared to all other levels and ratios.
- ❖ Among fertilizer management practices, the treatment receiving NPK fertilizer ratio of 3:1:1 (150 kg N, 50 kg P₂O₅ and 50 kg K₂O ha⁻¹) recorded higher gross monetary returns and higher net monetary returns (Rs. 73,955 and Rs. 34,229 ha⁻¹, respectively) over all other levels and ratios. Further higher B: C ratio of 1.86 was realized with the fertilizer ratio of 3:1:1 (150 kg N, 50 kg P₂O₅ and 50 kg K₂O ha⁻¹) over all other NPK fertilizer ratio (1.08 to 1.84, respectively).
- ❖ The pH of soil has decreased in all the NPK treatments and control, whereas ECE of soil increased in the plots applied with gypsum irrespective of NPK application.

- ❖ The available N, P and K content of soil were found to be high in nutrient applied plots compared to control plot where only gypsum was applied. Similarly, the availability of secondary and micronutrients viz; Ca, Mg, S, Zn, Cu, Fe, Mn and B were increased in the plots, which received gypsum and NPK + ZnSO₄ @ 20 kg ha⁻¹ along with farmyard manure @ 10 t ha⁻¹.
- ❖ Application of gypsum reduced the exchangeable sodium and ESP in surface (0-15 cm), whereas in subsurface (15-30 cm) these are increased after the harvest of first crop and then decreased at harvest of second crop.
- ❖ This clearly showed that in sodic soils, application of gypsum @100% GR and NPK (150:50:50 kg ha⁻¹) along with farmyard manure (10 t ha⁻¹) and ZnSO₄ @ 20 kg ha⁻¹ is more beneficial in enhancing the crop yield, crop productivity as well as soil fertility.

VII. REFERENCES

- ABDEL-FATTAH, M.K., 2012, Role of gypsum and compost in reclaiming saline sodic soils. *J. Agri. Vet. Sci.*, **1**(3): 30-38.
- ABROL, I.P. AND BHUMBLA, D.R., 1979, Crop response to differential gypsum applications in a highly sodic soil and tolerance of several crops to exchangeable sodium under field conditions. *Soil Sci.*, **127**: 79-85.
- ABROL, I.P. AND YADAV, J.S.P., 1988, Salt affected soils and their management. *FAO Soils Bulletin*, **39**.
- ABROL, I.P., CHHABRA, R. AND GUPTA, R.K., 1980, A fresh look at the diagnostic criteria for sodic soils. *International Symposium on Salt Affected Soils*, Feb. 18-21, CSSRI, Karnal, pp 142-147.
- AGARWAL, R.P. AND RAMMOORTHY, B., 1970, Morphological and chemical characteristics of alkali and normal soils from black and red soils of India. *Geoderma*, **4**: 403-415.
- AHMAD, S., GHAFOR, A., QADIR, M. AND AZIZ, M.A., 2006, Amelioration of a calcareous saline-sodic soil by gypsum application and different crop rotations. *Int. J. Agri. Biol.*, **8**(2): 142-146.
- ANAND SWARUP AND YADUVANSHI, N.P.S., 2000, Effects of integrated nutrient management on soil properties and yield of rice in alkali soils. *J. Indian Soc. Soil Sci.*, **48**(2): 279-282.
- ANAND SWARUP, 1982, Availability of iron, manganese, zinc and phosphorus in submerged sodic soil as affected by amendments during the growth period of rice crop. *Pl. Soil*, **66**: 37-43.
- ANAND SWARUP, 1991, Effect of gypsum, green manure, farmyard manure and zinc fertilization on the zinc, iron and manganese nutrition of wetland rice on a sodic soil. *J. Indian Soc. Soil Sci.*, **39**: 530-536.

- ANIL CHINCHMALATPURE, R., KHANDELWAL, M.K. AND GURURAJA RAO, G., 2008, Characterization and classification of salt affected soils of Samni farm, Bharuch district, Gujarat. *Agropedology*, **18**(2): 71-75.
- ARJUNAN, A. AND CHANDRASEKARAN, S., 1998, Tolerance of rice (*Oryza sativa* L.) in relation to salt uptake and yield. *Indian J. Pl. Physiol.*, **31**: 403-406.
- ARORA, C.L. AND SEKHON, G.S., 1981, Influence of soil characteristics on DTPA extractable micronutrient cations in some soil series of Punjab. *J. Indian Soc. Soil Sci.*, **29**(4): 453-461.
- ASHRAF, M. AND HARRIS, P.J.C., 2005. *Abiotic stresses plant resistance through breeding and molecular approaches*. Haworth Press, Binghamton, pp. 725 USA, ISBN 1-56022-965-9.
- BALLOLLI, S.S., 1987, Characterization and reclamation of salt affected soils of Bijapur district, Karnataka state. *M.Sc. (Agri.) Thesis*, submitted to University of Agricultural Sciences, Dharwad, pp 69-90.
- BALPANDE, S.S., DESHPANDE, S.B. AND PAL, K., 1996, Factors and processes of soil degradation in Vertisols of Poorna Valley, Maharashtra, India. *Land Degrad. Dev.*, **7**: 313-324.
- BANDYOPADHYAY, B.K., DUTT, S.K. AND BANDYOPADHYAY, A.K., 1985, Ionic balance and growth of rice under saline soil condition. *J. Indian Soc. Soil Sci.*, **33**: 346-351.
- BARDE, N.K. AND GOWALKAR, P., 1965, Studies on soils of semi arid region of North Gujarat. *J. Indian Soc. Soil Sci.*, **13**: 43-52.
- BARUAH, T.C. AND BARTHAHAKUR, H.P., 1999, In: *Text book of Soil Analysis*. Vikas Publishing House Pvt. Ltd., New Delhi.
- BASU, J. K. AND TAGORE, V. D., 1954, Land utilization surveys of saline soils of Bombay State. *J. Soil Water Conserv.*, **3**: 4-27.

- BEAR, F.E., 1964, *Chemistry of the soil*, 2nd Edn., American Chemical Society Monograph Series, Reinheld Publishing Corporation, New York, pp. 356.
- BHADRAPUR, T.G. AND SESHAGIRI RAO, T., 1979, The effect of seepage and water-logging on the development of saline and sodic soils in Tunga Bhadra project area of Karnataka. *J. Indian Soc. Soil Sci.*, **27**: 408-413.
- BHARADWAJ, V.P.K., OMANWAR, R.A., SHARMA, R.A. AND VISHWANATH, 1994, Long-term effects of continuous rotational cropping and fertilization on crop yields and soil properties – I, effects on crop yields and nutrients uptake. *J. Indian Soc. Soil Sci.*, **42**(2): 247-253.
- BHARDWAJ, K.K.R. AND ABROL, I.P., 1978, *National symposium, Nitrogen assimilation and crop productivity*. P. 83.
- BHARDWAJ, K.K.R., 1975, Survival and symbiotic characteristics of rhizobium in saline alkali soils. *Pl. Soil*, **43**: 377-385.
- BHARGAVA, G.P., 1979, *Soil and water quality surveys in a decade of research*. CSSRI-Publication, Karnal, pp. 22-34.
- BHARGAVA, G.P., ABROL, I.P. AND BHUMBLA, D.R., 1976, Note on the nomenclature of some salt affected soils in the Indo-Gangetic plains. *J. Indian Soc. Soil Sci.*, **24**: 81-83.
- BHASKAR, B.P. AND NAGARAJU, M.S.S., 1998, Characterization of some salt-affected soils occurring in the Chitravathi river basin of Andhra Pradesh. *J. Indian Soc. Soil Sci.*, **46**(3): 416-421.
- BHUMBLA, D.R., 1978, Salinity and alkalinity problem of arid regions of India. *Proc. Indian Nat. Sci. Acad.* **44**: 331-343.
- BINA DEVI, S. AND VARSHNEY, S.P., 1979, Available phosphorus in salt affected soils. *J. Indian Soc. Soil Sci.*, **27**: 383-396.

- BISWAS, T.D. AND GAWANDE, S.P., 1962, Studies on genesis of catenary soils on sedimentary formation in Chhatisgarh Basin of Madhya Pradesh-I. Morphology and mechanical composition. *J. Indian Soc. Soil Sci.*, **14**: 183-195.
- BLACK, C.A., 1965, *Methods of soil and plant analysis II*, No. 9 in the series, *Agron. Amer. Soc. Agro. Inc. Wisconsin*.
- CHALLA, O. AND GAIKWAD, M.S., 1987, Water relation characteristics of major soils of Dadra and Nagar Haveli. *J. Indian Soc. Soil Sci.*, **35**: 118-120.
- CHAUHAN, R.P.S. AND TRIPATHI, B.R., 1983, Reclamation studies on highly saline-sodic soil of semi-arid tract in Uttar Pradesh. *J. Indian Soc. Soil Sci.*, **31**: 587-595.
- CHAUHAN, R.P.S., 1995, Effect of amendments on sodic soil reclamation and yield and nutrient uptake of rice (*Oryza sativa*) under rice fallow rice system. *Indian J. Agril. Sci.*, **65**: 438-441.
- CHHABRA, R. AND THAKUR, N.P., 2000, Long-term study on phosphorus fertilization for rice-wheat cropping system in an alkali soil in the Indo-Gangetic plains. In: Long-term soil fertility experiments in Rice-Wheat cropping systems (Rice-Wheat Consortium), pp: 31-39. Abrol, I.P. (Edn.). Paper Series 6, New Delhi, India.
- CHHABRA, R., 1985, Crop response to phosphorus and potassium fertilization of a sodic soil. *Agron. J.*, **77**: 699-702.
- CHHABRA, R., ABROL, I.P. AND SINGH, M.V., 1981, Dynamics of phosphorus during reclamation of sodic soils. *Soil Sci.*, **132**(5): 319-324.
- CONWAY, T., 2001, Plant materials and techniques for brine site reclamation, plant materials technical note No 25, U.S. Department of Agriculture- Natural Resource Conservation Service, Bridger, Montana.

- COSTA, J.L., LYLEPRUNTU, B.R., MONTGOMERY, J.L., RICHARDSON AND ALESSI, R.S., 1991, Water quality effects on soils and alfalfa-II. Soil physical and chemical properties. *Soil Sci. Soc. Am. J.*, **55**: 203-209.
- CRUZ-ROMERO, G. AND COLEMAN, N.T., 1975, Reactions among calcium carbonate, carbon dioxide and sodium adsorbents. *Soil Sci. Soc. Am. Proc.*, **38**: 738-742.
- CSSRI, 2011, Vision 2030, Central Soil Salinity Research Institute (Indian Council of Agricultural Research), Karnal-132001, India (www.cssri.org).
- DAS, K.N., BASUMATARI, A. AND BORKOTOKI, B., 2012, Forms of sulphur in some rapeseed growing soil of Assam. *J. Indian Soc. Soil Sci.*, **60**(1): 13-19.
- DESHPANDE, M.V., 1985, Comprehensive study of physical, chemical and mineralogical properties of salt affected and adjacent normal Vertisol. *Ph D. Thesis*, submitted to University of Agricultural Sciences., Bengaluru.
- DHANE, S. AND SHUKLA, L.M. 1995, Distribution of DTPA extractable Zn, Cu, Mn and Fe in some soil series of Maharashtra and their relationship with some soil properties. *J. Indian. Soc. Soil Sci.*, **43**(4): 597-600.
- DHANYA, MATHEWS, V., PATIL, P.L. AND DASOG, G.S., 2006, Effect of nutrients and biofertilizers on yield and yield components of rice in coastal alluvial soil of Karnataka. *Karnataka J. Agril. Sci.*, **19**(4): 799-803.
- DINESH SHARMA, PARDEEP KUMAR SANGWAN, ISHWER SINGH AND AJIT SANGWAN, 2012, Influence of different nitrogen and phosphorus levels on profitability, plant nutrient content, yield and quality in basmati cultivars *Intern. J. IT, Engg. App. Sci. Res. (IJIEASR)*, **1**(1): 1-4.
- DUBEY, D.D., VERMA, G.P. AND SHARMA, O.P., 1983, Differences in the nature and properties between the salt-affected and normal Vertisol. *Curr. Agric.* **7**: 129-137.

- DUBEY, D.D., SHARMA, O.P. AND SHILPA, P.K., 1984, Formation and taxonomy of salt affected soils. *J. Indian Soc. Soil Sci.*, **32**: 146-149.
- EATON, E.M., 1950, Significance of carbonates in irrigation waters. *Soil Sci.* **69**: 123-133.
- FAO, 1974, Soil map of the world.FAO/UNESCO report.
- FENN, L.B. AND KISSEL, D.L., 1973, Ammonia volatilization from surface application of ammonia compounds on calcareous soils. *Soil Sci. Soc. Am. J.*, **37**: 855-859.
- GAIKAWAD, S.T., TAMGADGE, D.B. AND MESHRAM, R.S., 1985, Impact of landform on physico-chemical properties of soils of Bhandara district (M.P). *J. Maharashtra Agril. Univ.*, **11(2)**: 141-143.
- GANGAPPA, P.V., 1989, Nature of salt affected soils of Challakere taluk, Chitradurga district. *M.Sc. (Agri.) Thesis*, submitted to University of Agricultural Sciences, Bengaluru.
- GARG, V.K. AND JAIN, R.K., 1996, Effect of fuel wood plantation on some properties of sodic waste lands. *J. Trop. For. Sci.*, **9(2)**: 194-205
- GAWANDE, S.P. AND BISWAS, T.D., 1977, Characterization and classification of black soils developed on basalt in relation to micro-relief. *J. Indian. Soc. Soil Sci.*, **19(4)**: 223-238.
- GEETHA SIREESHA, P.V. AND NAIDU, M.V.S, 2013, Studies on genesis, characterization and classification of soils in semi-arid agro-ecological region: A case study in Banaganapalle Mandal of Kurnool District of Andhra Pradesh. *J. Indian. Soc. Soil Sci.*, **61(3)**: 167-178.
- GIRDHAR, I.K., 1993, Occurrence and properties of salt affected soils in India. In: Salt affected soils and crop production: A modern synthesis, Agro-Botanical publishers, Bikaner, India, pp7-30.

- GIRDHAR, I.K., 1996, Effect of leaching with waters of varying residual sodium carbonate, SAR and electrolytes concentration on properties of a *Haplustalf*. *J. Indian Soc. Soil Sci.*, **44**: 495-499.
- GIRDHAR, I.K., AND YADAV, J.S.P., 1982, Effect of magnesium rich water on soil properties, yield and chemical composition of wheat. *Soil Sci.*, **134**: 348-353.
- GOVINDARAJAN, S.V., MURTHY, R.S. AND NAGABHUSHANA, S.R., 1969, Problems and management requirements of some important soils of Thiruchengodu taluk in Salem district. *J. Indian Soc. Soil Sci.*, **17**: 357-367.
- GUPTA, I.C., 1973, Note on relationship between pH of saturated paste and 1:2 soil water suspension. *Indian J. Agric. Sci.*, **42**: 962.
- GUPTA, R.K. AND ABROL, I.P., 1990a, Salt affected soils, their reclamation and management for crop production, *Adv. Soil Sci.*, **11**: 283-288.
- GUPTA, R.K. AND ABROL, I.P., 1990b, Reclamation and management of alkali soils. *Indian J. Agril. Sci.*, **60**: 1-16.
- GURUPRASAD, M.S., 2005, Characterization of soils under Kabini track of Cauvery command area and rice response to amendments. *M.Sc. (Agri.) Thesis*, submitted to University of Agricultural Science, Bengaluru.
- HARRADINE, F. AND JENNY, H., 1958, Influence of parent material and climate on texture, nitrogen and carbon contents of virgin California soils. *Soil Sci.*, **85**(5): 235-243.
- HAYEE, A.M., SHAH, S.H., MALIK, M.A., SABIR, M.R. AND ALI, A., 1989, Effect of different levels of NPK on the growth and grain yield of two wheat varieties, *Pak. J. Agri. Sci.*, **26**(3): 236-240.
- HEBBARA, M., MANJUNATHA, M.V., RAVISHANKAR, G. AND PATIL, S.G., 2004, Leaching behavior of saline Vertisols under paddy cropping sequence. *J. Indian Soc. Soil Sci.*, **52**(3): 270-279.

- HEBBARA, M., VISWANATH, D.P., AND DEVARNAWADGI, S.B., 1992, Performance of tree species on marginally saline Vertisols of Tungabhadra project area. *J. Indian Soc. Soil Sci.*, **40**: 616-617.
- INDRA R. SINGH AND KAMERIYA, P.R., 2012, Characteristics of *Natric Trophants* occurring in semi-arid eco-region of Rajasthan. *J. Agric. Sci.*, **4**(8): 112-116.
- IQBAL, J., MEHDI, S.M., HUSSAIN, K., MAHMOOD, T. AND NIAZI, M.H.K., 1992, Growth response of rice and wheat to NH_4 -N rates in salt-affected soils, *Pak. J. Agri. Sci.*, **29**(3): 279-280.
- JACKSON, M.L., 1958, *Soil Chemical Analysis*. Prentice-Hall Inc., Englewood Cliffs, New Jersey, 498 pp.
- JACKSON, M.L., 1973, *Soil chemical analysis*. Practice Hall of India (Pvt.) Ltd., New Delhi.
- JAGTAP, P.B., PATIL, J.D., NIMBALKAR, C.A. AND KADLAG, A.D., 2006, Effect of micronutrient fertilizers on release of nutrients in saline sodic soil. *J. Indian Soc. Soil Sci.*, **54**(4): 489-494.
- JAGTAP, P.B., PATIL, J.D., NIMBALKAR, C.A. AND KADLAG, A.D., 2007, Influence of integrated nutrient management on soil properties and release of nutrients in a saline sodic soil. *J. Indian Soc. Soil Sci.*, **55**(2): 147-156.
- JAIN, G.L. AND SAXENA, S.N.P., 1975, Distribution of soluble salts and boron in relation to irrigation water. *J. Indian Soc. Soil Sci.*, **18**: 174-182.
- JANARDHANAN NAIR, T., PADMANABHAN NAMBIAR, E. AND MONEY, N.S., 1966, Studies on Keen-Raczowski measurements and their relation to soil test values in cultivated soils of Kerala. *Soils Fert.*, **30**: 297.
- JAYAKUMAR, M., BALASUBRAMANIAN, V. AND MANICKAM, T.S., 2012, Characterization of sodic soils of North Western zone of Tamil Nadu. *Madras Agric. J.*, **99**(10-12): 707-710.

- JENNY, H. AND RAYCHAUDHURI, S. P., 1960, *Effect of climate and cultivation on nitrogen and organic carbon reserves in Indian soils*. Indian Council of Agricultural Research, New Delhi, pp. 28-72.
- JOACHIM H.J.R. AND HUBERT VERPLANCKE, 2010, Effect of gypsum placement on the physico-chemical properties of a saline sandy loam soil. *Australian J. Crop Sci.*, **4**(7): 556-563.
- JOHN, M.K., CHUAH, S.H. AND NEUSELD, J.H., 1975, Analysis of micro and macro nutrients in soil and plant. *Anal. Letter*, **8**: 559.
- JOSE GERARDO LOPEZ-AGUIRRE, JAVIER FARIAS-LARIOS, JAIME MOLINA-OCHOA, SERGIO AGUILAR-ESPINOSA, MARIA DEL ROCIO FLORES-BELLO AND MARTIN GONZALEZ-RAMIREZ, 2007, Salt leaching process in an alkaline soil treated with elemental sulphur under dry tropic conditions. *World J. Agri. Sci.*, **3**(3): 356-362.
- KADU, D.R., PAL, D.K. AND DESHPANDE, S.B., 1993, Effect of low exchangeable sodium on hydraulic conductivity and drainage in shrink-swell soils of the Purna valley, Maharashtra. *Clay Res.*, **12**: 65-70.
- KAMIL, J. AND SHAINBERG, I., 1968, Hydrolysis of sodium montmorillonite in sodium chloride solutions. *Soil Sci.*, **106**: 193-199.
- KANTHALIYA, P.C. AND BHATT, P.L., 1991, Relation between organic carbon and available nutrients in some soils of sub-humid zone. *J. Indian. Soc. Soil Sci.* **38**: 781-792.
- *KANWAR, J.S. AND BHUMBLA, D.R., 1969, Physico-chemical characteristics of sodic soils of Punjab and Haryana and their amelioration by use of gypsum. *Agrokem Talajit*, **18**(Suppl): 325-330.
- *KANWAR, J.S. AND KANWAR, B.S., 1968, Quality of irrigation water. Trans. 5th Int. Cong. Soil Sci, **1**: 391-403.

- KANWAR, J.S. AND SEHGAL, J.L., 1962, Classification of saline sodic and normal soils of Kangra district. *J. Indian Soc. Soil Sci.*, **10**: 19-25.
- KAPOOR, B.S., SINGH, H.B., GOSWAMI, S.S., ABROL, I. P., BHARGAVA, G. P. AND PAL, D., 1981, Weathering of micaceous minerals in some salt affected soils. *J. Indian Soc. Soil Sci.*, **28**: 486-492.
- KASWALA, R.R. AND DESHPANDE, S.B., 1983, Physico-chemical and mineralogical characteristics of some coastal and inland soil series of south Gujarat-I. Physico-chemical characteristics. *J. Indian Soc. Soil Sci.*, **31**: 285-286.
- KATIGENAVAR, S. H., 1998, Studies on some of the physical characteristics of salt affected soils of Malaprabha and Ghataprabha command areas. *M. Sc. (Agri.) Thesis*, submitted to University of Agricultural Sciences, Dharwad.
- KATTI, V.M. AND RAO, T.S., 1979, Chemical characteristics of some salt affected soils in the Ghataprabha Left Bank Area, Karnataka. *Madras Agric. J.*, **66**: 192-194.
- KELLEY, W.P., 1951, *Alkali Soils*, ASC Monograph. III. Reinhold Publ. Corp., New York.
- KEWADE, A.D., RAVANKAR, H.N. AND PADOLE, V.R., 2005, Characterization of salt affected soils of Keliveli (Dist. Akola) from Purna valley by saturation extract analysis. *J. Soils Crops*, **15**: 90-95.
- KHARCHE, V.K., 1990, Evaluation of production potential of different soil for suggested proper land use in Saongi Watershed. *M.Sc. (Agri.) Thesis*, submitted to Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola.
- KHARCHE, V.K. AND PHARANDE, A.L., 2010, Land degradation assessment and land evaluation in Mula command of irrigated agro-ecosystem of Maharashtra. *J. Indian Soc. Soil Sci.*, **58**(3): 221-227.

- KORNDORFER, G.H. AND ANDERSON, D.L., 1993, Use and impact of sugar alcohol residues vinasse and filter on sugarcane production in Brazil. In: *Proceedings of International American Seminar*, Miami, USA, September 15-17, pp. 164-170.
- KOTUR, S.C., 1985, Chemical investigation of salt affected soils in Malaprabha and Ghataprabha river valley projects with emphasis on genesis. *Ph.D Thesis*, submitted to University of Agricultural Sciences, Bengaluru.
- KOTUR, S.C., AND SHESHAGIRI RAO, T., 1987, Relationship between exchangeable sodium percentage and sodium adsorption ratio in some salt affected soils. *J. Indian Soc. Soil Sci.*, **39**: 537-541.
- KOUR, S. AND JALALI, V.K., 2008, Forms of sulphur and their relationship in soils of different agro-climatic zones of Jammu region. *J. Indian Soc. Soil Sci.*, **56**: 309-312.
- KOVDA, V.A., BERG, C.V.D. AND HAGAN, R.M. (Ed)., 1973, In: *Irrigation, drainage and salinity*. An international source book. Hutchison/ FAO/UNESCO, London, p. 510.
- KRISHNAMURTHY, P. AND GOVINDARAJAN, P.V., 1977, Genesis and classification of associated red and black soils under Rajolibunda diversion irrigation scheme (Andhra Pradesh). *J. Indian Soc. Soil Sci.*, **25**(3): 293-246.
- KRISHNAMURTHY, K.G., 1993, Properties, genesis and classification of red soil of North Karnataka. *M. Sc. (Agri.) Thesis*, submitted to University of Agricultural Sciences, Dharwad.
- KULIGOD, V.B., SALIMATH, V.M., VIJAYSEKHAR, K. AND BALAKRISHNAN, P., 2002, Characterization and spatial and temporal variability of soil salinity in the Upper Krishna Project Command area, Karnataka. *J. Indian Soc. Soil Sci.*, **50**(2): 226-229.

- KUMAR, D., SWARUP, A. AND KUMAR, V., 1996, Influence of levels and method of N application on the yield and nutrition of rice in a sodic soil. *J. Indian Soc. Soil Sci.*, **44**(2): 259-263.
- KUMAWAT, B.L., 2000, Effect of subsurface compaction on soil physical properties water use efficiency, nitrogen utilization and crop yield in sandy soils of Rajasthan. *National Seminar on Development in Soil Science-2000 (Abstr.)* **2**: 318.
- KURI, H. F., 1979, Effect of dilution on soluble and exchangeable cations in salt-affected soils. *M.Sc. (Agri.) Thesis*, submitted to University of Agricultural Sciences, Bengaluru.
- LAKSHMI PRASANNA, V., 1991, Evaluation of soil fertility and quality characters of paddy varieties. *M.Sc. (Agri.) Thesis*, submitted to APAU, Rajendranagar, Hyderabad.
- LAKSHMINARAYANA MURTHY, Y.N., 2003, Chemistry of salt affected soils of southern Karnataka. *Ph. D Thesis*, submitted to University of Agricultural Sciences, Bengaluru.
- LAL BAHADUR, TIWARI, D.D., MISHRA, J. AND GUPTA, B.R., 2013, Nutrient management in rice-wheat sequence under sodic soil. *J. Indian Soc. Soil Sci.*, **61**(4): 341-346.
- LANDEY, R.J. AND MURTHY, R.S., 1967, Investigation on quality of irrigation waters in the Bhadra watershed, Hadagali, Bellary dist, Mysore state. *Indian J. Agron.*, **12**: 262-266
- LEVY, R. AND FEIGHONBAUM, S., 1977, Effect of dilution on soluble and exchangeable sodium in soils differing in mineralogy. *Geoderma*, **18**: 193-205.
- LINDSAY, W.L. AND NORVELL, W.A., 1978, Development of a DTPA soil test for Zn, Fe, Mn and Cu. *Soil Sci. Soc. Am. Proc.*, **42**: 421-428.

- MAHENDRA, A.C., 2007, Studies on reclamation of sodic soils through distillery spentwash. *M.Sc. (Agri.) Thesis*, submitted to the University of Agricultural Sciences, Dharwad.
- MAHMOODABADI, M., YAZDANPANA, N., SINOBAS, L.R., PAZIRA, E. AND NESHAT, A., 2013, Reclamation of calcareous saline sodic soil with different amendments (I): Redistribution of soluble cations within the soil profile. *Agri. Water Manag.*, **120**: 30-38.
- MAJI, B., CHATTERJI, S. AND BANDOPADHYAYA, B.K., 1993, Available iron, manganese, zinc and copper in coastal soils of Sunderbans, West Bengal in relation to soil characteristics. *J. Indian Soc. Soil Sci.*, **41**: 468-471.
- MALI, B.S., THENGAL, S.S. AND PATE, P.N., 2012, Physico-chemical characteristics of salt affected soil from Barhanpur, M.P., India. *Annals Biol. Res.*, **3**(8): 4091-4093.
- MALI, V.S., ZENDE, N.A. AND VERMA, U. K., 2002, Correlation between soil physico-chemical properties and available micronutrients in salt affected soils. *17th World Congress Soil Sci, Thailand*. 2220 (1-7).
- MALIK, M.A. AND SHAH, S.H., 1996, Response of wheat to nitrogen application grown under saline conditions. *J. Agril. Res.*, **11**: 40-43.
- MANDAL, A.K. AND SHARMA, R.C., 2010, Delineation and characterization of waterlogged and salt affected areas in IGNP command, Rajasthan for reclamation and management. *J. Indian Soc. Soil Sci.*, **58**(4): 449-454.
- MANZOOR, Z., AWAN, T.H., ZAHID, M.A. AND FAIZ, F.A., 2006, Response of rice crop (Super Basmati) to different nitrogen levels, *J. Ani. Pl. Sci.* **16**(1-2): 52-55.
- MARSH, A.S. AND SICEAMA, T.G., 1997, Use of formerly ploughed land in New England to monitor the vertical distribution of lead, zinc and copper in mineral soil. *Water, Air and Soil Poll.*, **95**: 75-85.

- MCKENZIE D.C., 1998, Soil pak for cotton growers, *Third edition, NSW Agriculture, ORANGE.*
- MEDIRATTA, J.C., BANSAL, K.N. AND GUPTA, G.P., 1985, Characterization of some salt-affected soils of Harsi command area. *J. Indian Soc. Soil Sci.*, **33**: 214-217.
- MEHDI, S.M., SARFRAZ, M. AND IBRAHIM, M., 2007, Fertilizer requirement of wheat in recently reclaimed soils. *World applied. Sci. J.*, **2**(6): 559-568.
- MEHDI, S.M., SARFRAZ, M., IBRAHIM, M. AND MAHMOOD, K. 2008, Fertilizer requirement of different crop rotations in recently reclaimed soils. *American-Eurasian J. Agric. Environ. Sci.*, **3**(2): 179-186.
- MEHTA, K.K., 1983, *Reclamation of alkali soils of India.* Oxford and IBH publishing Co., New Delhi.
- MEHTA, K.K., YADAV, J.S.P. AND KUMBHARE, D.S., 1981, Reclamation of alkali soils, *Indian Farming*, **31**: 18-19.
- MICHAEL, P. AND PAUL, J., 2002, Growing Turf on salt-affected sites, technical note No-519, Utah State University Extension Service.
- MOHAMED, K. AND ABDEL-FATTAH, 2012, Role of gypsum and compost in reclaiming saline-sodic soils. *J. Agri. Vet. Sci.*, **1**(3): 30-38.
- MOHR, E.C.J. AND VAN BARM, F.A., 1954, Tropical Soils. Van Hoore, Netherlands. p 489.
- MORE, S.D., SHINDE, J.S. AND MALEWAR, G.U., 1988, Characterization of some salt affected soils of Purna command area of Maharastra, *J. Indian Soc. Soil Sci.*, **36**(1): 146-150.
- MOTAMED, M.K., ASADI, R., REZAEI, M. AND AMIRI, E., 2008, Response of high yielding rice varieties to NaCl salinity in greenhouse circumstances. *African J. Biotech.*, **7**(2): 3866-3873.

- MRUTHUNJAYA, S. AND KENCHANNA GOWDA, S.K., 1993, Physico-chemical properties of some salt affected soils of Vanivilas command area of Karnataka. *Mysore J. Agril. Sci.*, **27**(4): 349-355.
- MUHR, S. R., DATTA, N. P., SANKARSUBRAMONEY, H., LELEY, V. K. AND DOUNAHEVE, R. L., 1965, *Soil testing in India*, Published by United States Agency for International Development Mission to India, New Delhi.
- MURTHY, A.S.P., 1988, Distribution, properties and management of Vertisols in India. *Adv. Soil. Sci.*, **8**: 151-209.
- MURTHY, R.S. AND LANDEY, R.J., 1967, Field and laboratory characterization of some saline and alkali soils in the Tungabhadra watershed, Hadagalli Tawaki, Bellary district, Mysore state. *Indian J. Agron.* **12**: 335-340.
- MURTHY, R.S., HIREKERUR, L.R., DESHPANDE, P.B. AND VENKATA RAO, B.V., 1982, Benchmark soils of India, National Bureau of Soil Survey and Land Use Planning, Nagpur, p 374.
- MZEZEWA, J., GOTOSA, J. AND NYAMWANZA, B., 2003, Characterisation of a sodic soil catena for reclamation and improvement strategies. *Geoderma*, **113**: 161-175.
- NADEEM, M.Y., QURESHI, R.H. ASLAM M. AND AHMAD, N., 1995, Interactive effect of salinity and nitrogen on the yield of wheat. *Pak. J. Agril. Sci.*, **32**: 160–167.
- NAJAR, G.R., AKHTAR, FARIDA, RAHMAN, F.H. AND SINGH, S.R., 2005, Macro and micronutrient status of some salt affected soils of Jammu and Kashmir. *Indian Agriculturist*, **49** (3/4): 239-243.
- NAKAYAMA, F.S., 1970, Hydrolysis of CaCO_3 , Na_2CO_3 , NaHCO_3 and their combinations in the presence and absence of external CO_2 source. *Soil. Sci.*, **109**: 391-398.

- NAYAK, D. C., SARKAR, D. AND DAS, K., 2002, Forms and distribution of pedogenic iron, aluminium and manganese in some Benchmark soils of West Bengal. *J. Indian. Soc. Soil Sci.*, **50**: 89-93.
- NAYANAKA, V.G.D., VITHARANA, W.A.U, AND MAPA, R.B. 2010, Geostatistical analysis of soil properties to support spatial sampling in a paddy growing Alfisol. *Tropical Agril. Res.*, **22**(1): 34-44.
- NIMBALKAR, A.M., 1990, Evaluation of physical and chemical characteristics of soils of the Purna Valley of Maharashtra. *M.Sc. (Agri.) Thesis*, submitted to Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola.
- NITANT, H.C. AND BHUMBLA, D.R., 1974, Urea transformation in salt affected and normal soils. *J. Indian Soc. Soil Sci.*, **22**: 234-239.
- NITANT, H.C. AND DARGAN, K.S., 1974, Influence of nitrogenous fertilizers on yield and nitrogen uptake of wheat in saline sodic soils. *J. Indian Soc. Soil Sci.*, **22**: 121-124.
- PAGE, A.L., MILLER, R.H. AND KENAY, D.R., 1982, *Methods of Soil Analysis*. Part-2 Soil Science Society of America, Inc, Publis., Madison, Wisconsin, USA.
- PAL, D. K., 1985, Potassium release from muscovite and biotite under alkaline conditions. *Pedology*, **35**: 133-146.
- PAL, D.K. AND MANDAL, R.C., 1980, Crop response to potassium in sodic soils in relation to potassium release behavior in salt solutions. *J. Indian Soc. Soil Sci.*, **28**(3): 347-354.
- PAL, D.K. AND DESHPANDE, S.B., 1987, Genesis of clay minerals in a red and black soil complex of southern India. *Clay Res.* **6**: 6-13.
- PANSE, V.G. AND SUKHATME, P.V., 1978, *Statistical Methods for Aricultural Workers*, ICAR, New Delhi.

- PARASURAMAN, S. AND JAYARAJ, S., 1982, Distribution of total and available N, P and K of the major soil series of profiles of black soils of Coimbatore district, Tamil Nadu. *Madras Agric. J.*, **69**: 825-829.
- PATAGUNDI, M.S., CHANNAL, H.T., AND SATYANARAYANA, T., 1996, Characterization of some salt affected soils of Thungabhadra Left Bank Command, Karnataka. *Karnataka J. Agric. Sci.*, **9**(2): 226-230.
- PATHAK, S.R. AND PATEL, N.K., 1980, Study of some physicochemical characteristics of salt affected soils of Kaira district, Gujarat state. *J. Indian Soc. Soil Sci.*, **28**(1): 31-37.
- PATIL, K. P., PANDYA, R. R., MALIWAL, G. L., PATEL, K. C., KAMANI, V. P. AND GEORGE, V., 2004, Heavy metal content of different effluents and their relative availability in soils irrigated with effluent waters around major industrial sites of Gujarat. *J. Indian Soc. Soil Sci.*, **52**: 89-94.
- PIPER, C.S., 1966, *Soil and Plant Analysis*, Inter-science Publishers, Inc., New York. pp. 368.
- POONIA, S.R. AND BHUMBLA, D.R., 1973, Some physico-chemical characteristics of salt-affected and adjacent normal soils of Rothak district. *J. Indian Soc. Soil Sci.*, **21**: 335-341.
- PURANIK, R.B., BARDE, N.K. AND BALLAL, D.K., 1972, Studies on some saline-alkali soils of Akola district, Maharashtra state. *PKV Res. J.*, **1**: 51-58.
- RAGHUWANSHI, S.R.S., TIWARI, S.C., PRABHA, S., RAGHUWANSHI, O.P.S., SASODE, D.S. AND UMAT, R., 2011, Characterization of salt affected soils of Bhind district of Madhya Pradesh. *J. Indian Soc. Soil Sci.*, **59**: 388-391.
- RAJENDRA BHANWARIA, KAMERIYA, P.R. AND YADAV, B.L., 2011, Available micronutrient status and their relationship with soil properties of Mokala soil series of Rajasthan. *J. Indian Soc. Soil Sci.*, **59**(4): 392-396.

- RAM, D., RAM, T. AND SUBHASH CHAND, 2010, Characterization and classification of flood prone soils and eastern plains of Rajasthan for their corrective measures. *J. Indian Soc. Soil Sci.*, **58**(3): 228-232.
- RAO, D.L.N. AND BATRA, L., 1983, Ammonia volatilization from applied nitrogen in alkali soils. *Pl. Soil.*, **70**: 219.
- RAVI KUMAR, M.A., 2006, Soil resource characterization of 48A Distributary of Malaprabha Right Bank command for sustainable land use planning. *M. Sc. (Agri.) Thesis*, submitted to University of Agricultural Sciences, Dharwad.
- RAVI KUMAR, M.A., PATIL, P.L. AND DASOG, G.S., 2007, Mapping of nutrient status under 48A distributary in Malaprabha right bank command of Karnataka by geographic information system technique-I: Major nutrients. *Karnataka J. Agril. Sci.*, **20**: 735-737.
- RENGASAMY P. AND SUMMER M.E., 1998, Process involved in sodic behavior, Australian sodic soils: Distribution properties and management. CSIRO, Melbourne, 35-50.
- RICHARDS, L.A., (Ed), 1954, *Diagnosis and improvement of saline and alkaline soils*. USDA Handbook No. 60, U.S. Soil Salinity Laboratory, U.S. Department of Agriculture and Oxford & IBH Pub. Co. Pvt. Ltd., New Delhi. pp 160.
- ROY, B.B. AND LANDEY, R.T., 1962, Studies on red and lateritic soils of Mord watershed area of Raigarh district. *J. Indian Soc. Soil Sci.*, **32**(6): 294-302.
- SABIR GUL KHATTAK, IZHAR UL HAQ, ABDUL MALIK, MUHAMMAD JAVED KHATTAK AND NAVEEDULLAH, 2007, Effect of various levels of gypsum application on the reclamation of salt affected soil grown under rice followed by wheat crop. *Sarhad J. Agric.*, **23**(3): 675-680.
- SAHU, G.C. AND DASH, S.S., 1993, Characterization and classification of salt affected coastal soils of Astaranga, Orissa. *J. Indian Soc. Soil Sci.*, **41**: 138-144.

- SAHU, G.C. AND MISHRA, K.N., 1997, Morphology, characteristics and classification of soils of an irrigated flood plain in the eastern coastal region. *J. Indian Soc. Soil Sci.*, **45**: 152-156.
- SAHU, G.C., NANDA, S.K. AND PANDE, N., 1986, Genesis, characteristics and classification of coastal saline soils of Orissa. *J. Indian Soc. Soil Sci.*, **34**: 322-328.
- SALLIAH, T. AND PATHMARAJAH, S. 2003. An economic analysis of salinity problems in the Mahaweli river system irrigation scheme, EEPSEA (Economy and environment program for southeast Asia), Sri Lanka.
- SANTHY, P., JAYASHREE, SHANKAR, S., MUTHUVEL, P. AND SELVI, D., 1998, Long – term fertilizer experiments – status of N, P and K fractions in soil. *J. Indian Soc. Soil Sci.*, **46**: 395-398.
- SARWAR, G., SCHMEISKY, H., HUSSAIN, N., MUHAMMAD, S., IBRAHIM, M. AND EHSAN SAFDAR, 2008, Improvement of soil physical and chemical properties with compost application in rice-wheat cropping system. *Pak. J. Bot.*, **40**(1): 275-282.
- SATISH KUMAR, Y.S. AND NAIDU, M.V.S., 2012, Characteristics and classification of soils representing major land forms in vadamalapeta mandal of Chittoor district, Andhra Pradesh. *J. Indian Soc. Soil Sci.*, **60**: 63-67.
- SATYANARAYANA, V., VARA-PRASAD, P.V., MURTHY, V.R.K. AND BOOTE, K.J., 2002, Influence of integrated use of farmyard manure and inorganic fertilizer on yield and yield components of irrigated lowland rice. *J. Pl. Nutr.*, **25**: 2081-2090.
- SCHOONOVER, W.R., ELBGABOLY AND NAGRIT, H., 1957, A case study of some Egyptian saline soils. *Hilgardia*, **26**: 566-596.
- SEHGAL, J.L., 1991, Soil-site suitability evaluation for cotton. *Agropedology*, **1**: 49-63.

- SEHGAL, J.L., BHUMLA, D.R. AND DHINGZA, D.R., 1968, Soils of the Sutlej and flood basin areas in the Punjab. *J. Indian Soc. Soil Sci.*, **6**: 241- 247.
- SHAHZADA MUNAWAR MEHDI, MUHAMMAD SARFRAZ, SYED TOUQUEER ABBAS, GHULAM SHABBIR AND JALIL AKHTAR, 2011, Integrated nutrient management for rice-wheat cropping system in a recently reclaimed soil. *Soil Environ.*, **30**(1): 36-44.
- SHAINBERG, I. AND LETEY, J., 1984, Response of soils to sodic and saline conditions. *Hilgardia*, **152**: 1-57.
- SHARMA, B.M. AND JHA, S.N., 1989, Comparative studies on some salt affected soils. *J. Indian Soc. Soil Sci.*, **37**: 524-531.
- SHARMA, D.L., MOGHE, V.B. AND MATHUR, C.M., 1968, Salinity and alkalinity problem and fertility status of soils of Pali district (Rajasthan). *J. Indian Soc. Soil Sci.*, **16**: 263-275.
- SHARMA, D.P., MEHTA, K.K. AND YADAV, J.S.P., 1981, Effect of reclamation practices on soil properties and crop growth on farmers fields – A case study. *J. Indian Soc. Soil Sci.*, **29**(3): 356-360.
- SHARMA, J.P. AND RAY CHOUDHARI, C., 1988, Soil landforms relationship in a basaltic terrain. *J. Indian Soc. Soil Sci.*, **36**(4): 755-760.
- SHARMA, O.P., DUBEY, D.D. AND VERMA, G.P., 1986, Factors responsible for development of salt affected soils of lower Narmada valley. *J. Indian Soc. Soil Sci.*, **36**: 198-201.
- SHARMA, O.P., SHARMA, D.N. AND MINHAS, P.S., 1997, In 25 years of research and management of salt affected soils and use of saline water in Agriculture. pp. 64-84. CSSRI, Karnal.
- SHARMA, P.K., ANIL SOOD., SETIA, R.K., TUR, N.S., DEEPAK MEHRA, AND HARPINDER SINGH, 2008, Mapping of macronutrients in soils of Amritsar district (Punjab) – A GIS approach. *J. Indian. Soc. Soil Sci.*, **56**(1): 34-41.

- SHARMA, R.C., 1998, Nature, extent and classification, In: Agricultural Salinity management in India (N.K. Tyagi and P.S. Minhas, Eds). Central Soil Salinity Research Institute, Karnal.
- SHARMA, R.L., MANDAL, A.K. AND RANBIR SINGH, 2011, Delineation and characterization of waterlogged and salt affected soils in Gandak command area of Bihar for reclamation and management. *J. Indian Soc. Soil Sci.*, **59**(4): 315-320.
- SHARMA, R.P., MEGH SINGH AND SHARMA, J.P., 2003, Correlation studies on micronutrient vis-à-vis soil properties in some soils of Nagpur district in semi-arid region of Rajasthan. *J. Indian Soc. Soil Sci.*, **51**(4): 522-527.
- SHARMA, S.S., TOTAWAT, K.C. AND SHAYMPURA, R.L., 2005, Characterisation and classification of salt affected soils of southern Rajasthan. *J. Indian Soc. Soil Sci.*, **52**(3): 209-214.
- SHARMA, S.S., TOTAWAT, K.L. AND SHYAMPURA, R.L., 2004a, Characterization and classification of salt affected soils of Rajasthan. *J. Indian Soc. Soil Sci.*, **52**: 209-214.
- SHARMA, V.K., SHARMA, P.D., SHARMA, S.P., ACHARYA, C.L. AND SOOD, R.K., 2004b. Characterization of cultivated soils of Neogal watershed in North-West Himalayas and their suitability for major crops. *J. Indian Soc. Soil Sci.*, **52**: 63-68.
- SINGH, N.T., BHUMBLA, D.R. AND KANWAR, J.S., 1969, Effect of gypsum alone and in combination with plant nutrients on crop yield and amelioration of a saline sodic soil. *Indian J. Agric. Sci.*, **39**: 1-9.
- SINGH, N.T., BHUMBLA, D.R. AND RANDHAWA, N.S., 1975, Forms of inorganic phosphate in sodic soils. *J. Indian Soc. Soil Sci.*, **23**: 353-356.
- SINGH, R.N., SINGH, R.N.P. AND DIWAKAR, D.P.S., 2000, Characterization of old alluvial soils of sone basin. *J. Indian Soc. Soil Sci.*, **48**(2): 352-357.

- SINGH, S., SATYAVIR SINGH, DHANKHAR, O.P. AND ABHA TIKKOO, 2005, Importance of gypsum in crop production under sodic water use in light textured soils of Haryana. *J. Indian Soc. Soil Sci.*, **53**(2): 249-253.
- SINGH, S.B., CHAABRA, R. AND ABROL, I.P., 1980, Effect of soil sodicity on the yield and chemical composition of cowpea grown for fodder. *Indian J. Agric. Sci.*, **50**: 852-856.
- SITANGGANG, M., RAO, Y.S., NAYAN AHMED AND MAHAPATRA, S.K., 2006, Characterization and classification of soils in watershed area of Shikohpur, Gurgaon district. *Haryana. J. Indian Soc. Soil Sci.*, **54**: 106-110.
- SOMANI, L.L., 1990, *Alkali soils- their reclamation and management*. Divya Jyothi Prakashan, Jodhpur.
- SRINATH, K., 1979, A study of physico-chemical characteristics of some salt-affected soils in Tunga Bhadra River Valley Project Left Bank Canal Area. *M.Sc. (Agri.) Thesis*, submitted to University of Agricultural Science, Bengaluru.
- SRINIVASA RAO, C.A., SUBAIAH, G.V. AND PILLAI, R.N., 1991, Nutrient status of black soils of Telugu Ganga Project Area in Nellore district of Andhra Pradesh. *Andhra Agril. J.*, **38**: 201-205.
- SRINIVASA, N., 1999, Characterization and reclamation of sodic soils in Vishveshwaraiah canal tract of Cauvery command area. *Ph.D Thesis*, submitted to University of Agricultural Science, Bangalore.
- SRIVASTAVA, A.K. AND SRIVASTAVA, O.P., 1993, Soluble cations and anions in relation to soil pHs and E_{Ce} in *Typic natraqualf*. *J. Indian Soc. Soil Sci.*, **42**: 435-437.
- SUBBAIAH, G.V. AND MANICKAM, T.S., 1992, Genesis and morphology of Vertisols development on different parent material. *J. Indian Soc. Soil Sci.*, **40**(1): 150-155.
- SUBBIAH, B.V. AND ASIJA, G.L., 1956, Rapid procedure for the estimation of the available nitrogen in soil. *Curr. Sci.*, **25**: 259-260.

- SUBRAMANIAN, K.S. AND KUMARASWAMY, 1989, Fertilization on chemical properties of soil. *J. Indian Soc. Soil Sci.*, **37**: 171-173.
- SUMA, R. AND SAVITHA C.M., 2010, Impact of saline soil management: Practices on soil health and paddy cultivation in Mandya, Karnataka. *Indian Res. J. Ext. Edu.*, **10**(2): 29-31.
- SUMMER, M.E., 1993, Sodic soils: New perspectives. *Australian J. Soil Res.*, **31**: 683-750.
- SUNITHA, N., 2008, Characterization of soil properties and performance of beetroot crop in salt affected soil of Dodda Seebi tank command area, Tumkur district, *M. Sc. (Agri.) Thesis*, submitted to University of Agricultural Science, Bengaluru.
- SUNITHA, N., BASAVARAJA, P.K., DHANANJAYA, B.N., NARASIMHA REDDY, P.N. AND SUDIR, K., 2010, Characterization of salt affected soil of Dodda Seebi tank command area. *Karnataka J. Agril. Sci.*, **23**(2): 354-357.
- SURIBABU, K., BHANU PRASAD, V., SESHAGIRI RAO, M. AND PRASUNA RANI, P., 2002, Nutrient status of soils of A. Konduru mandal in Krishna district of Andhra Pradesh. *Andhra Agril. J.*, **49**: 155-158.
- SZABLOCS, I., 1993, Nature, origin, formation, identification and classification of salt affected soil. In: salt affected soil and crop production: A modern synthesis, Agro-Botanical publishers, Bikaner, India. Pp: 33-51.
- SZABOLCS, I., 1989, *Salt affected soils*. CPC Press, Florida, 1-46 p.
- TAWANDE, S.K., PATIL, J.D. AND ZENDE, G.K., 1976, The forms and contents of sulphur in soils of Maharashtra state. *J. Maharashtra Agril. Univ.*, **1**(1): 1-6.
- TIWARI, K.N., KUMAR, A. AND PATHAK, A.N., 1983, Characterization of salt-affected soils in central alluvial region of Uttar Pradesh. *J. Indian Soc. Soil Sci.*, **31**: 272-280.

- TOTAWAT, K.L., 1991, Effect of zinc smelter effluent and soil amendments on metabolic cations build up in soil and yield of crop plants. *Annl. Arid Zone*, **31**: 255-258.
- TRILOK NATH RAI, KEDAR NATH RAI, PRASAD, S.N., SHARMA, C.P., MISHRA, S.K. AND GUPTHA, B.R., 2010, Effect of organic amendments, bioinoculants and gypsum on the reclamation and soil chemical properties in sodic soils of Ettawah. *J. Soil Water Conser.*, **9**(3): 197-200.
- VANESSA, N.L.W., RICHARD, S.B.G., RAM, C.D., BRIAN, W.M., AND SURENDER, M., 2006, Carbon dynamics in salt-affected soils, the 18th world congress of soil science from 9-15 July 2006, Philadelphia, Pennsylvania.
- VERMA, T.P., SINGH, S.P., RAM GOPAL, R.P. AND DHANKAR, R.V.S., 2012, Characterization and evaluation of soils of Trans Yamuna area in Etawah district, Uttar Pradesh for Sustainable land use. *Agropedology*, **22**(1): 26-34.
- VIJAYA KUMAR, M., LAKSHMI, G.V. AND MADHUVANI, P., 2013, Appraisal of soil fertility status in salt affected soils of Ongole division, Prakasam district of Andhra Pradesh. *J. Indian. Soc. Soil Sci.*, **61**(4): 333-340.
- WALIA, C.S. AND RAO, Y.S., 1996, Genesis, characteristics and taxonomic classification of some red soils in Bundelkhand region of Uttar Pradesh. *J. Indian Soc. Soil Sci.*, **44**(3): 470-481.
- WALKLEY, A.J. AND BLACK, C.A., 1934, An examination of wet acid method for determining soil organic matter and proposed modification of chromic acid titration method. *J. Soil Sci.*, **37**: 29-38.
- WASEEM, H., 2004, Effectiveness of application rate of Ca²⁺ for reclamation of different textured saline-sodic soils. *M.Sc. Thesis*, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan.
- WISCHMEIER, W.H., JOHNSON, C.B. AND CROSS, B.V., 1971, A soil erodability nomograph for farmland and construction sites. *J. Soil Water Conser.*, 189-192.

- YADAV, J.S.P., 1973, Annual report, All India Coordinated Research Project on Water Management and Soil Salinity, Central Soil Salinity Research Institute, Karnal, India, pp 23.
- YADUVANSHI, N.P.S. AND SWARUP, A., 2005, Effect of continuous use of sodic irrigation water with and without gypsum, farmyard manure, pressmud and fertilizer on soil properties and yields of rice and wheat in a long term experiment. *Nut. Cycl. Agroecosystems*, **73**: 111-118.
- YADUVANSHI, N.P.S., 2003, Substitution of inorganic fertilizers by organic manures and the effect on soil fertility in a rice-wheat rotation on reclaimed sodic soil in India. *J. Indian Soc. Soil Sci.*, **140**: 161-168.
- YADUVANSHI, N.P.S., 2009, Integrated nutrient management for rice-wheat cropping system in reclaimed sodic soil, *Res. J. Pl. Ani. Sci.*, **24**(1): 65-71.
- YERRISWAMY, A.N., 1996, Studies on salt affected soils of Upper Krishna Project Command Area. *M.Sc. (Agri.) Thesis*, submitted to University Agricultural Sciences, Dharwad.
- YERRISWAMY, A.N., CHANNAL, H.T., PATAGUNDI, M.S. AND SATYANARAYANA, T., 1997, Salt affected soils of Upper Krishna command area, Karnataka. I. Physical and chemical characteristics. *Agropedology*, **7**: 32-39.
- YERRISWAMY, A.N., CHANNAL, H.T., PATAGUNDI, M.S. AND SATYANARAYANA, T., 1998, Macro and micro nutrient status of some salt affected Vertisols of Upper Krishna command area (Karnataka). *Agropedology*, **8**: 35-40.

*Originals not seen